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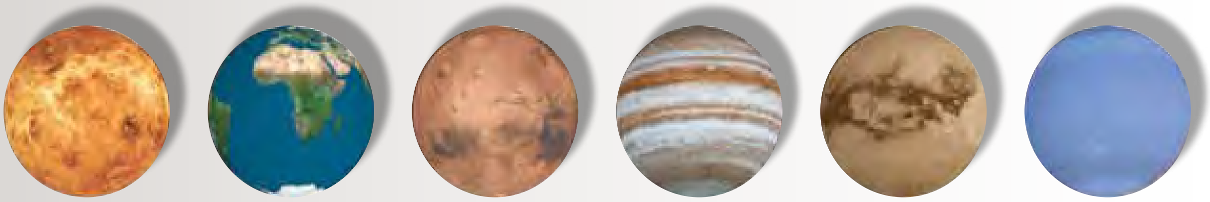
9th INTERNATIONAL PLANETARY PROBE WORKSHOP

Toulouse, France June 18–22, 2012 www.planetaryprobe.eu

Short Course: Probe Science Instrumentation Technologies June 16–17

Abstract Book



Bienvenue !

Welcome to Toulouse ! L’Institut Supérieur de l’Aéronautique et de l’Espace (founded 1909), the oldest French Grande Ecole dedicated to aeronautics and space, is pleased and honored to host the ninth meeting of the International Planetary Probe Workshop.

In attendance at IPPW-9 is an abundance of participants, a varied program, and ample opportunities for discussion of future collaborations. This year’s theme is Space Probe Instrumentation, as reflected in our Short Course and many of the oral and poster presentations. Our community has been very busy over the past year; all of our work has generated an outstanding set of presentations and posters that you will encounter in the next four and a half days.

We are pleased to welcome an international group of scientists, technologists, engineers, mission designers, and policy makers to IPPW-9. Our committees have worked very hard in organizing the logistics for the workshop, planning the program, soliciting and evaluating nominees for the Al Seiff Award, and coordinating opportunities for student participation.

Ideally situated in the heart of Southern France, between the Mediterranean and the Atlantic Ocean, the cosmopolitan and enthusiastic Ville Rose joyously mixes heritage and lifestyle, great cultural events and festival pleasures. Toulouse is an absolute must for everyone wanting to explore France. At once both modern and proud of the legacy of its past, open and radiant, you are bound to be seduced by the incomparable Toulousain lifestyle, coupled with the wealth of its cultural heritage. Your stay in Toulouse will certainly be a pleasurable one.

We encourage you to attend as many oral and poster sessions as possible, in order to benefit from the world-wide planetary probe mission experts attending IPPW-9. We have scheduled a relaxing poster session on Tuesday evening. To better associate the submitted posters with their sessions, we will also have posters available in conjunction with each session. In keeping with agendas at previous IPPWs, we have scheduled parallel oral sessions only on Thursday. Our conveners will coordinate their timing so it will be possible to move back and forth between the parallel sessions in the morning and afternoon. Of interest to our student and early career attendees is a professional development session, scheduled for mid-day on Thursday.

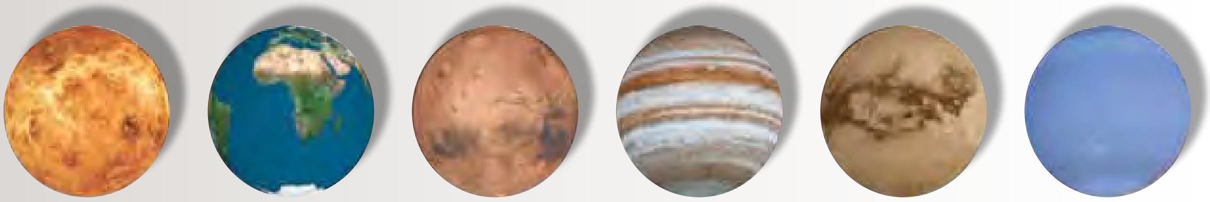
Since IPPW-9 is indeed a workshop, we also urge you to take advantage of the numerous opportunities during coffee breaks, lunches and social activities to build collaborative partnerships with other workshop participants. In addition, the IPPW-9 sponsors have generously funded a large number of students who would be interested in meeting the working planetary probe participants to gain a better understanding of how to build a future career in this exciting field. We are very encouraged to have a sizeable student population with us!

On Friday, 22 June, there will be a presentation on the plans for IPPW-10 in 2013, in the United States. We encourage you to attend this talk to learn about your next opportunity to join our community. In this time of transition for many of our Agencies, it is all the more valuable for us to reconnect with our colleagues and celebrate our strong planetary probe foundations. We encourage you to learn and enjoy our 9th International Planetary Probe Workshop.

Let’s make it a great week !

Bernie Bienstock
NASA Jet Propulsion Laboratory
IPPW-9 International Organizing Committee

David Mimoun
Institut Supérieur de l’Aéronautique
et de l’Espace



IPPW-9 Premium Sponsors

Supporting Organizations

Program at a glance: Monday 18, June 2012

Monday, 18 June 2012

Time	Duration	Session	Id	Description	Conveners
08:00	30			Registration/Coffee	
08:30	30	Session 1		Opening Welcome and Logistics D. Mimoun – Logistics B. Bienstock/J-P. Lebreton – Opening of IPPW-9	Bernie Bienstock Jean-Pierre Lebreton
09:00	30	Opening; Outlook for Probe Missions		M. Wright: Presentation of the Al Seiff Award R. Braun: Opportunity Taken: The Value of Diverse Career Experience (Invited)	
09:30	25			P. Bousquet: French Contributions to Entry and Surface Missions (Invited)	
09:55	25		195	L. Colangeli: The ESA Science Program for the Progress of European Society (Invited)	
10:20	30			Coffee	
10:50	25		194	J. Reuther: The NASA Space Technology Program and Support of EDL Technologies (Invited)	
11:15	25		164	K. Fujita: An Overview of Japan's Planetary Probe Mission Planning (Invited)	
11:40	25		132	O. Korablev: Outlook for planetary probe missions in Russia (Invited)	
12:05	25		112	J. Cutts: The Next Fifty Years of Planetary Exploration with Probes (Invited)	
12:30	90			Lunch	
14:00	25	Session 2	47	O. Mousis: A Saturn Entry Probe Mission: What can be learnt from the measurements of heavy noble gas abundances and isotropic ratios (Invited)	Tom Spilker
14:25	25	Giant Planets	138	N. André: Missions to Uranus: Exploring the Origins and Evolution of Ice Giant Planets (Invited)	Athena Coustenis
14:50	25		116	D. Lebleu: Exploring the depths of Saturn (Invited)	
15:15	25		141	P. Wurz: Mass spectrometric investigation of the atmospheres of giant planets (Invited)	
15:40	20		168	T. Spilker: Saturn Entry Probe Potential for Uranus and Neptune Missions	
16:00	20		35	V. Parmentier (Student): Planetary probes into giant planets : what will we learn ?	
16:20	20		170	J. Lebreton: The Schumann Resonance: a tool for the in situ and remote sensing exploration of the deep atmosphere of giant planets	
16:40	30			Coffee	
17:10	25	Session 3	31	R. Lorenz: The Titan Mare Explorer (TiME) Discovery Mission (Invited)	Jeff Hall
17:35	20	Titan	183	P. Beauchamp: The organic aerosols of Titan's atmosphere	Francesca Ferri
17:55	20		124	F. Sohl: Scientific rationale of future Titan landing sites	
18:15	20		71	C. Lange: TiNet - A Concept Study for a Titan Geophysical Network	
18:35				Evening Activity	

Program at a glance: Tuesday 19, June 2012

Tuesday, 19 June 2012

Time	Duration	Session	Id	Description	Conveners
08:00	30			Registration/Coffee	
08:30	20	Session 3, cont.	163	R. Thissen: Orbitrap Mass Analyser: a Tool for Titan Complex Molecular Content Exploration	Jeff Hall
08:50	20	Titan	127	A. Brandis: Modeling and Validation of CN Violet Radiation Relevant to Titan Entry	Francesca Ferri
09:10	20		8	J. Hall: Titan Montgolfiere Balloon Analysis and Design Using Computational Fluid Dynamics Simulations	
09:30	20		22	J. Nott: Lessons for Titan balloons from recent terrestrial experience	
09:50	20		14	G. Dorrington: Buoyancy Estimation of a Titan Aerostat	
10:10	20		133	D. Akita: A Simple Entry, Descent, and Floating System for Planetary Ballooning	
10:30	30			Coffee	
11:00	20	Session 4	102	S. Limaye: Exploring Venus With Balloons - Science Objectives and Recent Technical Advances	Colin Wilson
11:20	20	Venus	169	C. Wilson: The European Venus Explorer (EVE) 2010 mission proposal	Anita Sengupta
11:40	20		104	A. Sengupta: Development of a Venus Entry System for the Surface and Atmospheric Geochemical Explorer	
12:00	20		154	C. Kelley: Parachute Development for Venus Missions	
12:20	20		41	D. Mehoke: Technologies for a Long Duration Lander on the Surface of Venus	
12:40	90			Lunch	
14:10	25		144	E. Venkatapathy: A Game Changing Approach to Venus In-Situ Science Missions Using Adaptive Deployable Entry and Placement Technology (Invited)	
14:35	25		153	S. Limaye: Sampling the Unexplored Regions of Venus (Invited)	
15:00	20		69	G. Dorrington: Venus Atmospheric Platform Options Reconsidered	
15:20	25	(Session 7A Invited)	6	M. Barucci: MarcoPolo-R: Asteroid Sample Return Mission (Invited: Airless & Primitive Bodies)	
15:45	30			Coffee	
16:15	25	Session 5	74	F. Ferri: ExoMars Atmospheric Mars Entry and Landing Investigations and Analysis (AMELIA) (Invited)	Karl Edquist
16:40	20	Mars	140	T. Walloschek: ExoMars EDM Mission and Development Status	Jill Prince
17:00	20		29	M. Munk: Status of the Mars Entry Atmospheric Data System (MEADS) Hardware and Data Reconstruction Effort	Ozgur Karatekin
17:20	20		101	T. White: Status of the MEDLI Integrated Sensor Plug (MISP) Hardware and Data Reconstruction Effort	
17:40	20		37	M. Perkinson: Mission Architecture and System Design of a Mars Precision Lander	
18:00	20		72	M. Chapuy: Vision-based navigation solution for soft and precise landing on Mars	
18:20	130	Poster Session		Poster Session/Wine & Cheese	Ioana Cozmuta
20:30		End of day			

Program at a glance: Wednesday 20, June 2012

Wednesday, 20 June 2012

Time	Duration	Session	Id	Description	Conveners
08:00	30	Session 5, cont. Mars		Registration/Coffee	
08:30	20		136	B. Van Hove (Student): Obtaining Atmospheric Profiles during Mars Entry	Karl Edquist
08:50	20		52	M. Sorgenfrei (Student): Revision of a Parametric Entry, Descent, and Landing Design Tool for Mars Exploration	Jill Prince
09:10	20		134	D. Bonetti: Optimum Sizing for Design of Mars Probes	Ozgur Karatekin
09:30	20		4	A. Korzun (Student): Conceptual Modeling of Supersonic Retropropulsion Flow Interactions and the Relationship to System Performance	
09:50	20		79	A. Guelhan: Improvement of Experimental and Numerical Tools for Safe and Controlled Martian Entry	
10:10	30			Coffee	
10:40	20		86	R. Kovalev: Experimental and Numerical Simulation of Martian Entry Conditions	
11:00	20		3	A. Kolesnikov: Simulation of heat transfer and surface catalysis for EXOMARS entry conditions	
11:20	20		155	K. Fujita: Technology Development toward Mars Aeroflyby Sample Collection	
11:40	20		19	T. Chabot: Robust Autonomous Aerobraking Strategies	
12:00	20		51	A. Sanchez Hernandez (Student): IPPW-9 Dynamical study of the aerobraking technique in the atmosphere of Mars	
12:20	210	Field Trip		Bag Lunch/Field Trip	
19:00		Visit		Visit of cite de l'espace	
20:30	180	Banquet		Banquet	
23:30		End of day			

Program at a glance: Thursday 21, June 2012

Thursday, 21 June 2012

Time	Duration	Session	Id	Description	Conveners	Session	Id	Description	Conveners
08:00	30			Registration/Coffee				Registration/Coffee	
08:30	25	Session 6A Cross-Cutting Technologies I	175	N. Cheatwood: NASA Game Changing Development Program - Entry, Descent, and Landing Overview (Invited)	Aaron Morris	Session 6B Earth Entry & Sample Return	40	J. Bouilly: RASTAS SPEAR : Radiation Shape Thermal Protection Investigation for High Speed Re-Entry (Invited)	Michelle Munk
08:55	20		21	K. Edquist: Supersonic Retropropulsion Technology Development in NASA's Entry, Descent, and Landing Project	Ali Guelhan		192	T. Yamada: Post-Flight Analysis of the Hayabusa Sample Return Capsule	Todd White
09:15	20		89	J. Del Corso: Aerothermal Ground Testing of Flexible Thermal Protection Systems for Hypersonic Inflatable Aerodynamic Decelerators			28	M. Munk: Multi-Mission Earth Entry Vehicle Development by NASA's In-Space Propulsion Technology (ISPT) Project	Jean Muylaert
09:35	20		63	J. Knittel (Student): Optimized StarBody Waverider Shapes for Lifting Aerocapture			46	L. Ferracina: PHOEBUS a hypervelocity entry demonstrator	
09:55	20		166	A. Saunders: Sub-scale, high-altitude testing of parachutes; a low-cost methodology for the characterisation of parachutes for planetary entry			2	G. Bailet (Student): Re-entry Platform for In-flight Demonstration and In-situ Measurement	
10:15	20		178	B. Tutt: Modeling the Structural Performance of Hypersonic Inflatable Aerodynamic Decelerators			103	A. Sengupta: Orion Multi-Purpose Crew Vehicle Drogue Parachute Performance	
10:35	30			Coffee				Coffee	
11:05	20		137	N. Cheatwood: HEART Flight Test Overview			176	M. Murbach: The Small Payload Quick Return (SPQR) System as a Testbed for Future Planetary Probe Missions	
11:25	20		148	D. Jurewicz: Design and Verification of Full-Scale Inflatable Aeroshell Structures for Hypersonic Applications			84	J. Heilimo: Adapting Mars Entry, Descent and Landing System for Earth	
11:45	20		109	A. Calomino: Flexible Thermal Protection System Design and Margin Policy			131	K. Hirai: IR&D Studies of Light Weight Ablator for Future Reentry Capsule Heatshield	
12:05	20		110	J. Del Corso: Flexible Thermal Protection System Development for Hypersonic Inflatable Aerodynamic Decelerators			76	H. Ritter: ESA TPS Activities for Sample Return Missions	
12:25	20		185	E. Venkatapathy: Deployable Aeroshell Technology Maturation Plan and Progress: Enabling Planetary In-Situ Science Missions			24	R. Lorenz: A Review of Apollo Splashdowns - Influence of Cavity Resurge on Stability	
12:45	95			Lunch/Professional Development	Ioana Cozmuta			Lunch/Professional Development	Ioana Cozmuta
14:20	20	Session 7A Airless & Primitive Bodies	45	B. Houdou: The European Lunar Lander: A Human Exploration Precursor Mission	Louise Prockter	Session 7B Cross-Cutting Technologies II	96	R. Trautner: ESA supported Chip and ASIC Technology Developments for Exploration Missions including Planetary Probes	Dan Empey
14:40	20		118	E. Zaunick: Innovative Visual Navigation Solutions for ESA's Lunar Lander Mission	Jens Biele		7	L. Deutsch: NASA Space Communications and Navigation Support to Planetary Probe Missions	Jose Santos
15:00	20		87	R. Garcia: Farside Explorer mission project and internal seismic structure of the Moon			30	B. Dachwald: Development and Testing of a Maneuverable Subsurface Probe That Can Navigate Autonomously Through Deep Ice	Kelly Geelen
15:20	20		120	G. Orlando: Application of Simultaneous Localization and Mapping algorithm to Terrain Relative Navigation for Lunar Landing			82	C. Pearson (Student): Investigating the Composition of Enceladus via Primary Lander and Underwater Microorganism Explorer (ICEPLUME)	
15:40	20		149	R. Gowen: A low cost penetrator mission to study lunar volatiles			114	D. Bonetti: Robust and Autonomous Aerobraking Strategies	
16:00	30			Coffee				Coffee	
16:30	20		81	S. Tardivel (Student): A simple, robust and adaptable strategy for ballistic landings on small binary bodies			98	M. Adler: Low-Density Supersonic Decelerator Technology Demonstration Mission	
16:50	20		25	S. Ulamec: Lander Concepts for MarcoPolo-R			99	I. Clark: Development and Testing of a New Family of Low-Density Supersonic Decelerators	
17:10	20		67	A. Rivkin: MERLIN: Mars-Moon Exploration, Reconnaissance and Landed Investigation			11	C. Tanner (Student): Fluid-Structure Interaction Analyses of a Tension Cone Inflatable Aerodynamic Decelerator	
17:30	20		161	L. Prockter: Roadmap for and potential science return of a Europa Lander Mission			139	G. Molera Calves: VLBI and Doppler tracking of Venus Express spacecraft	
17:50	20		151	R. Gowen: An astrobiology Payload Complement for a Europa Penetrator			172	G. Swanson (Student): Instrumentation for the Characterization of Inflatable Structures	
18:10	20		147	S. Vijendran: Design of an Astrobiology Penetrator and Delivery System			182	A. Guarneros Luna (Student): A Flight Technology Demonstration of a Space Plug and Play Avionics (SPA) Module for Future Planetary Probes	
19:00	120	IOC dinner							
21:00		End of day							

Program at a glance: Friday 22, June 2012

Time	Duration	Session	Id	Description	Conveners
08:00	30			Registration/Coffee	
08:30	5	Session 8 Closing		Introduction - P. Papadopoulos	David Mimoun
08:35	35		80	B. Johns : Austerity In the Age of Innovation (Invited)	Periklis Papadapolous
09:10	30			Student Awards Presentations - S. Ruffin	
09:40	30			Coffee	
10:10	35			IPPW-9 Summary - P. Bousquet	
10:45	15			IPPW-9 IOC Report - B. Bienstock	
11:00	15			Open Forum - D. Mimoun	
11:15	15			Introduction of IPPW-10 - P. Papadopoulos	
11:30	5			Closing and Farewell - D. Mimoun	
11:35		End of day			

Oral Presentations

Session 1: Opening; Outlook for Probe Missions

P. Bousquet: French Probe Mission Planning

French contributions to entry and surface missions

Pierre W. BOUSQUET
Head of Planetology and Microgravity project office CNES, email :
pierre.bousquet@cnes.fr

In the general case, planetary exploration has followed a logical trend: planets or small bodies were first visited remotely through one or several fly-bys, before technological progress made orbit insertion, and continuous observation, possible. The next step has been landing on those bodies, which has opened the way to in-situ measurements. The ultimate improvement is represented by bringing samples back to Earth, but such missions are still in a pioneering phase.

The possibilities offered by in-situ missions are very diverse:

- interpretation and calibration of remote sensing data, "the ground truth",
- detailed analysis of local features, down to microscopic level,
- access to the subsurface, trough drilling or radar survey,
- in depth characterisation, through seismology measurements, or radar tomography in the case of small bodies.

Early in-situ robotic missions took place on the Moon, on Venus and on Mars in the 60's and the 70's. However, the last decade was a golden age for these missions with impressive successes of missions on Titan and on Mars, and the development of several exciting missions which should materialise in the coming years. Landing missions are fairly complex: they often need several modules, telecommunication relay capacities, a very high level of resiliency and can be submitted to stringent planetary protection requirements. As a consequence, most of these missions belong to the high cost range of planetary exploration, difficult to reach within the budget possibilities of a single national space agency such as CNES.

We will describe in our presentation how, together with French scientific laboratories, we contribute to in-situ missions, by providing various types of instruments, and also on a case by case basis by getting involved in lander system development, or in operations. These contributions take place quite naturally from a European perspective within the frame of ESA led missions, but also through bilateral cooperation with NASA, Roscosmos and JAXA.

As far as system activities are concerned, CNES has built-up a broad range of competences :

- Landers for small bodies, in cooperation with DLR, such as Philae for the Rosetta mission, and the on going development of Mascot which will be delivered to an asteroid by JAXA's Hayabusa 2 spacecraft;
- Rover autonomous navigation; for example the ExoMars 2018 rover navigation software is based is built upon algorithms developed at CNES;
- Operations : Philae's Science Operation and Navigation Center (SONC), and the remote control center of the ChemCam and SAM-GC instruments of the MSL mission, called FIMOC, are both located in our Toulouse technical centre;
- Aerodynamics at entry; we have built up an extensive simulation and test expertise since the ARD demonstration mission, and are currently developing a sensor for measuring the radiative fluxes on the backshell of ExoMars demonstration capsule, planned for 2016;
- Balloons for atmospheric missions, where we work on technology for Titan and Venus applications.

For instrumentation, French planetology and exobiology laboratories, with the support of CNES expertise and R&D program, has delivered state of the art hardware to a large number of on-going or decided in-situ missions. They will contribute to the investigation of an extensive set of bodies of the Solar System (Titan, Mars, Phobos, a Comet nucleus, the Moon, and asteroids). The principal instrument families where major experience has been accumulated are the following:

- Chromatograph columns,
- Laser spectroscopy,
- Hyperspectral microscopic imagers,
- Seismometers,
- Ground Penetrating Radars.

Finally, the perspectives for the next decade will be highlighted by presenting our main R&T efforts on instrumentation such as

- Miniaturised and power reduced technologies;
- Further integration of spectrometry and imaging;
- High resolution mas spectrometer based on the Orbitrap concept;
- New scientific capacities such as Laser induced Fluorescence for organic material characterisation, and in-situ dating.

The ESA Science Program for the progress of European society

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The Science and Robotic Exploration Directorate is in charge of developing the so-called “Science Mandatory Programme”, the only mandatory element of ESA, and, therefore, both a flagship and a symbol for the Agency. Both long-term science planning and mission calls are bottom-up processes, relying on broad community input and peer review. Through this programme, ESA must implement challenging scientific projects and promote advancement in technologies that individual European nations cannot obtain on their own.

The ESA Science Programme has allowed European scientists to score key “firsts”. This is true also in the field of probing planetary objects, e.g., with the successful landing of the ESA – Huygens probe (part of the NASA-ESA-ASI Cassini-Huygens mission) on Titan in 2005. ESA (alone or in partnership with other Agencies) is present in the Solar System with a fleet of spacecraft: Mars Express and Venus Express study and monitor planets; Cluster, SOHO, Hinode and Proba-2 investigate the Sun and the effects of emitted energetic particles and radiation in the interplanetary medium and on planetary bodies. Rosetta will allow soon unprecedented investigations of comet 67P/Churyumov-Gerasimenko, both remotely and in situ. The ESA-JAXA BepiColombo two-spacecraft mission will be launched in 2015 with destination Mercury. Integrated multi-point and multi-object observations allow an innovative view about the rules governing our Solar System and ultimately drive a revolution in our comparative understanding of planetary bodies, including the Earth.

The Cosmic Vision program is since 2005 the implementation tool to prepare the scientific missions for the period 2015-2025. Following the first call in 2007 for Medium (M) and Large (L) missions, Solar Orbiter and Euclid have been selected as “M1” and “M2” missions, respectively, in 2011. The Jupiter Icy Moon Explorer (JUICE) has been selected as “L1” in May 2012; this mission will guarantee a leading role to ESA in placing the new milestone in the exploration of outer planets and will prepare for future probing of Jovian moons by landers. At the second call for M-missions in 2010, EchO, LOFT, STE-QUEST and MarcoPolo-R have been selected for assessment. MarcoPolo-R is studied to collect samples from a primitive Near Earth Asteroid to be returned to Earth for laboratory analyses. The “M3” mission down-selection is planned for mid 2013.

J. Reuther: The NASA Space Technology Program and Support of EDL Technologies (Invited) (194)

The NASA Space Technology Program and Support of EDL Technologies

The NASA Space Technology Program (STP), as part of NASA's Office of Chief Technologist (OCT), covers a wide spectrum of space technology investments from low Technology Readiness Level (TRL) activities to high TRL in-space technology demonstrations. STP includes ten specific space technology programs, each with a large number of projects, studies and other activities. The guiding principles for all STP programs and projects are as follows:

- **Investment Guidance:** Strategic guidance for technology investments adhere to NASA's Strategic Plan, the NASA Space Technology Grand Challenges and NASA's Space Technology Roadmaps. Further investment determination is provided through consultation from NASA's Mission Directorates and Offices.
- **Full spectrum of Investments:** Spanning a comprehensive spectrum of innovation and technology advancement activities, investments include: low to high TRL development, student fellowships, university grants, concept studies, prize competitions, technology proof of concepts, and flight demonstrations.
- **Crosscutting and Transformational Technologies:** STP projects seek technologies that have crosscutting appeal, providing space technology solutions for multiple capabilities and for multiple customers/missions. STP seeks focused innovation and technology initiatives that are not incremental or evolutionary, but are instead disruptive, inspiring entirely new capabilities or missions, and that are revolutionary, changing the technical approach to solving long standing capability goals. Technology investments will meet the needs of future NASA missions, those of other government agencies, and those of the commercial space enterprise.
- **Competitive Peer-Review and Selection:** STP programs will develop their varied technology portfolio using competed solicitations open to NASA Centers, other government agencies, academia and industry. The philosophy is to find the best ideas and best people wherever they may reside.
- **Structured Project Execution:** Projects are held to a high standard in terms of the value proposition they offer. Projects will adhere to: clear start and end dates; strictly defined budgets; and delivering against clearly defined technical and programmatic milestones. Project Managers will be provided with significant management authority coupled with significant project accountability.
- **Infuse Rapidly or Fail Fast:** All projects will seek to move quickly towards technology maturation and infusion, taking on a greater informed risk tolerance to achieve a rapid cadence of definitive successes or failures. We do not avoid failure, but instead fail fast, learn and move on. We increase the dependency upon demonstrating a successful technology infusion customer as the TRL advances.
- **Reposition NASA on the cutting edge of technology:** Enforce technical rigor; push the boundaries of technology advancement; seek disruptive crosscutting innovation; rapid paced project oriented approach; drive toward technology infusion or fail quickly along the way; and support NASA, other government agencies, the commercial aerospace sector and the nation's economic future.

Within this broad set of programs and projects, STP currently makes significant investments in EDL technologies including: LDSD, HIAD, ADEPT, Woven TPS, ALHAT, and MEDLI. Future plans call for additional EDL activities as STP continues to lead all NASA efforts in terms of EDL future investments. Details regarding specific current STP EDL investments as well as potential future investments will be discussed.

An Overview of Japan's Planetary Probe Mission Planning

Kazuhisa Fujita*
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An overview of Japan's future planetary probe missions and associated technology development programs are presented. Following success of the asteroid explorer "Hayabusa", JAXA is now planning a new asteroid sample return mission named "Hayabusa-2". The target asteroid for Hayabusa-2 is a C-type asteroid, which is thought to have much more organic matters and water than S-type asteroids like Itokawa that Hayabusa visited. Also, Hayabusa-2 will challenge new technologies such as an impact or as well as improving the technologies of Hayabusa. The sample return capsule of Hayabusa-2 will be equipped with accelerometers and temperature sensors to reveal hypersonic flight environments during a superorbital reentry. Hayabusa-2 is currently in phase-C of development, and planned for launch in 2014.

The Moon lander SELENE-2 is planned as a follow-on mission of Kaguya (SELENE). The current plan covers a lander and a rover to demonstrate high-precision autonomous guidance, obstacle avoidance, and imaging navigation for safely soft-landing on the planetary surface, since these technologies are essential for exploration of not only moon but also mars or other planets. The SELENE-2 is currently in phase-B of development, and planned for launch before the middle of 2010's.

MELOS (an acronym of Mars Exploration with Lander-Orbiter Synergy) is Japan's new and ambitious plan for a series of Mars exploration missions. The ultimate goal of the MELOS series missions is to understand the solid planet, the surface processes, the atmosphere, and its surrounding plasma environment as one integrated system. This, of course, requires multiple missions of orbiters and landers, equipped with various instruments. The first mission of the MELOS series, MELOS1, is currently entertained for launch around 2020. The mission consists of two elements: a climate orbiter and an entry-descent-landing (EDL) demonstrator. The EDL demonstrator will primarily perform experiments of engineering aspects, while a small portion of its payload will be offered to scientific experiments. Current proposals for the EDL demonstrator include a small rover, a stationary lander, an airplane, and a powered paraglider to enable the interior-structure study, the astro-biological experiments, and the surface-geology study. The selection will take place in this year. We welcome cooperation proposals from the world Mars science community and/or contributed instruments that require and benefit from MELOS1's platforms.

The unique proposals currently entertained for future Mars and Venus probe missions are a Mars aerocapture demonstrator mission, a Mars Aeroflyby Sample Collection (MASC) mission, and a Venus balloon mission. In a mission scenario of MASC, an atmospheric entry vehicle of aero-maneuver capability is flown into the Martian atmosphere, collects the Martian dust particles as well as atmospheric gases during the guided hypersonic flight, exits the Martian atmosphere, and is inserted into a parking orbit from which a return system departs for the earth to deliver dust samples. In order to accomplish controlled flight and successful orbit insertion, aeroassist orbit transfer technologies are introduced into the vehicle's guidance and control system. The system analysis is performed to assess feasibility of the MASC system and to make a conceptual design, finding that the MASC system is feasible at the minimum system mass of 600 kg approximately.

O. Korablev: Outlook for planetary probe missions in Russia (Invited) (132)

Outlook for planetary probe missions in Russia

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Russian planetary probe missions, planned and including Phobos-Grunt will be reviewed. For Phobos-Grunt mission the Phobos landing vehicle and the re-entry rocket/capsule will be described in more detail. The next lunar/planetary missions in preparation are Luna-Resource and Luna-Globe polar landings. The current status of the mission and of the development of landing modules and the science instrumentation will be presented.

The failure of the Phobos-Grunt mission led to profound changes in the Russian planetary exploration programme. The implementation phases of such missions like Mars-Net and Venera-D have been postponed to after 2015. Still the major results of the assessment studies for these projects will be reported, along with proposed smaller asteroid mission and the considered reflight of Phobos-Grunt. The cooperation with European projects, including ExoMars, and Ganymede lander initiative considered in L-class mission will be discussed.

J. Cutts: The Next Fifty Years of Planetary Exploration with Probes (Invited) (112)

The Next 50 years of Planetary Exploration with Probes

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NASA's Mariner 2 spacecraft was launched on August 8th, 1962 and made a successful flyby of Venus on December 14, 1962. This first successful planetary mission heralded 50 years of planetary exploration involving NASA, and the space agencies of the then Soviet Union, Europe and Japan. This presentation looks back at some of the highlights of these 50 years, focusing particularly on probe and lander missions, assessing some of the key scientific, technical and programmatic drivers. It then looks forward at the opportunities in the next 50 years as the new spacefaring nations, including China and India, reach out to the planets and the potential for a second Golden Age of planetary exploration beckons.

Session 2: Giant Planets

O. Mousis: A Saturn Entry Probe Mission: What can be learnt from the measurements of heavy noble gas abundances and isotropic ratios (Invited) (47)

A SATURN ENTRY PROBE MISSION: WHAT CAN BE LEARNT FROM THE MEASUREMENTS OF HEAVY NOBLE GAS ABUNDANCES AND ISOTOPIC RATIOS

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We discuss the constraints that can be inferred on the formation conditions of the outer solar system from the measurements of heavy noble gas abundances and isotopic ratios (^{3}He, ^{4}He, ^{20}Ne, ^{22}Ne, ^{36}Ar, ^{38}Ar, ^{80}Kr, ^{82}Kr, ^{83}Kr, ^{84}Kr, ^{86}Kr, ^{128}Xe, ^{129}Xe, ^{130}Xe, ^{131}Xe, ^{132}Xe, ^{134}Xe, ^{136}Xe) by a high sensitivity mass spectrometer aboard a shallow probe in Saturn's atmosphere. Noble gases are excellent tracers for investigating the origin and the evolution of major solar system reservoirs of volatiles. Ar, Kr and Xe have been sampled in the atmospheres of Venus, Earth, Mars and Jupiter. In contrast, these species have been found to be strongly empoverished in Titan's atmosphere and the mechanism at the origin of their depletion still remains unknown. The sampling of the heavy noble gas abundances in Saturn's atmosphere will tell if the mechanism at the origin of their depletion in Titan occurred prior or after the satellite's formation. The measurement of Ar, Kr and Xe in subsolar abundances in Saturn's atmosphere would indicate that the primordial nebula was already depleted in noble gases at the formation location of Saturn and its satellite system. On the other hand, the measurement of Ar, Kr and Xe in solar abundances in Saturn's atmosphere would support the hypothesis that these species were retained in the gas phase (likely in the form of XH_3^+ complexes with X = Ar, Kr and Xe), impeding them to be incorporated in planetesimals during the cooling of the disk. Alternatively, the measurement of Ar, Kr and Xe in supersolar abundances in Saturn would be consistent with the hypothesis of delivery of noble gas-rich planetesimals to the giant planet and would imply that Titan's atmospheric depletion occurred after its formation. These measurements, used together with those expected to be made in 2014 by the Rosetta spacecraft on the short-period comet 67P/Churyumov-Gerasimenko, will provide new constraints on the formation conditions of planetesimals in the outer part of the primordial nebula. Isotopic ratios of noble gases have been measured in situ for Earth and in SNC meteorites for Mars. They show some solar attributes, as represented by the solar wind, as well as depletions indicative of escape processes or "nebular" fractionation processes. Studies of these isotopic ratios have shown that Earth is composed of volatiles presumably delivered at different epochs of the solar system evolution. He and Ne are expected to have been gravitationally captured by the Earth at early epochs while Ar, Kr and Xe would have been delivered later by exogeneous sources such as comets or asteroids. Measurement of the noble gas isotopic ratios in Saturn will be then important to infer the connection between the noble gas reservoirs in the solar system (refractory and icy material) and giant planet atmospheres. It will also provide additional constraints on the different sources and sinks that have shaped the atmospheres of the terrestrial planets.

N. André: Missions to Uranus: Exploring the Origins and Evolution of Ice Giant Planets (Invited) (138)

Missions to Uranus: Exploring the Origins and Evolution of Ice Giant Planets

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In contrast to the gas giants Jupiter and Saturn, Uranus and Neptune are often termed ice giants to account for the importance of ices (methane, water, ammonia) in their composition. Our understanding of these ice giants is significantly incomplete, with a number of fundamental questions unanswered. There is growing interest in interplanetary missions to these ice giants within the world-wide scientific community, particularly in missions to Uranus which is easier to access than Neptune and has unique qualities such as having its rotation axis being almost parallel to its orbital plane. Uranus Pathfinder is a mission concept proposed to ESA in response to its 2010 call for medium-class (M) missions. The mission proposed to explore the fundamental processes at work in the planet itself (its interior and atmosphere) and in its planetary environment (magnetosphere, satellites, and rings). The mission would provide observations and measurements that are vital for understanding the origin and evolution of Uranus as an Ice Giant planet, providing a missing link between our Solar System and planets around other stars. Although ultimately unsuccessful in the medium-class mission call, Uranus Pathfinder attracted considerable international support and received very positive reviews. Missions to Uranus remain high on the planetary science agenda within NASA, surviving recent programmatic reviews and funding cuts. In this talk we describe the science case for a mission to Uranus, the challenges in reaching and doing science at such a distant object, and the mission profiles that have been proposed and studied thus far.

Exploring the depths of Saturn

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The necessity for in-depth exploration of giant planets has been stressed since the very first IPPW. Among others, presentations from Sushil Atreya are in memories of the probe community, which has repeatedly proposed missions to probe the Giant Planets, such as the KRONOS proposal in the frame of ESA Cosmic Vision Call in 2007.

Now, new technological development in Europe for two key technologies revives the opportunity for such a mission.

Ablative Thermal Protection system had been developed by NASA in the golden age of space exploration, for GALILEO and PIONER VENUS. Some material of this Carbon phenolic material are still available in the USA, but the unavailability of the Giant Planet Facility test range does not allow to verify the material behavior after decades of storage. ESA has initiated development of an ablative material devoted to sample return mission (see paper of H. Ritter at IPPW8). Application for entry into Giant Planet atmospheres could be also added as a target for the development of this material.

Power generation for mission far from the Sun is also a design driver. Powerful RTG and ASRTG have been developed and used by NASA for Solar System exploration. As far as probes are concerned, PIONNER VENUS and HUYGENS have benefited from primary battery development in the frame of GALILEO. Now, the updated ExoMars mission considers the use of a small-sized RTG developed in Russia, delivering a quite low power but allowing for an interesting easier accommodation within a probe for a long-lived mission.

The paper will present some missions concepts for Saturn in-depth exploration, derived from the KRONOS proposal, but considering the use of these new developments. Such mission could be deeper analysed in the frame of future call for mission, enabling Europe, in a broad sense, to contribute to the exploration of Outer Planets. Potential application of such a mission concept to Uranus and Neptune will also be presented.

P. Wurz: Mass spectrometric investigation of the atmospheres of giant planets (Invited)

Mass spectrometric investigation of the atmospheres of giant planets

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Abstract

When trying to understand the present state of our solar system with its variety of planetary objects, one is confronted with a few major scientific questions: i) to understand how the physical and chemical processes determine the characteristics of planetary objects; ii) to investigate how planetary systems originate and evolve; iii) to discover how the laws of physics and chemistry can lead to the diverse phenomena observed in the Solar System; and iv) to determine how and where life evolved, and in what ways it modifies its planetary habitat. For all these scientific questions knowledge of the chemical composition is an important element because the composition is a direct result of major Solar System processes. The giant planets with their primitive atmospheres are of special interest since their composition is very similar to the Sun's, thus their study may allow conclusions about the composition of the gas disk during planetary formation.

The composition of a planetary atmosphere can be measured either via remote sensing techniques, or *in situ* on a probe descending through the atmosphere. Either method has its advantages and disadvantages. The presentation will be restricted to the discussion of *in situ* measurements by mass spectrometers. Such instruments are very versatile, are able to measure quantitatively the abundance of any species over large dynamic range, and allow for isotopic measurements. Mass spectrometer capabilities can be augmented with the addition of enrichment cells (e.g. for noble gases), with chromatographic columns for chemical pre-separation, with aerosol collectors – pyrolysers, and others. We will review the state-of-the-art in this field and summarise possible future directions of instrumentation in this field.

Saturn Entry Probe Potential for Uranus and Neptune Missions

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The recent US Planetary Science Decadal Survey (PSDS) recommends a Saturn atmospheric entry probe mission for inclusion in NASA's New Frontiers Program, and placed relatively high priority on an atmospheric entry probe as a part of a future flagship mission to Uranus. Although a lower priority, a mission to Neptune and Triton was recommended as a scientifically rich mission for the future. Atmospheric entry probes at any of the giant planets fit into a grand scheme of giant planet exploration that makes breakthrough progress not just in giant planet research, but in solar system origins research and exoplanet research as well. The instrumentation carried on a Saturn probe mission that addresses the Tier 1 science objectives and some Tier 2 objectives, specified in the PSDS, could also provide critical data at the ice giant planets Uranus and Neptune. It is likely that those instruments, with little or no modification, could provide the requisite data in the appropriate regions of the ice giant atmospheres. Those data are described in the Atkinson *et al.* white paper describing the role of giant planet entry probes in planetary science [1].

On the engineering side, it appears that atmospheric entry systems designed for a Saturn entry probe would be sufficient, and not egregious overkill, for entry into the ice giants' atmospheres as well. Despite Saturn's much larger mass than the ice giants, various other aspects such as planetary rotation rates, obliquities, bulk densities and atmospheric scale heights, and expected approach circumstances and heliocentric distances, contribute to a smaller than expected range of entry conditions at the three planets.

This paper will discuss the science objectives for entry probe missions to Saturn, Uranus, and Neptune, investigations and instrumentation for addressing those objectives, and their applicability to the different atmospheres. It will also describe the aspects of these planets and entry probe missions that contribute to the applicability of a single design approach.

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

1. Atkinson, D.H. et al., "Entry Probe Missions to the Giant Planets", white paper to the US PSDS, available at http://www8.nationalacademies.org/ssbsurvey/publicview.aspx .

V. Parmentier (Student): Planetary probes into giant planets : what will we learn ? (35)

Planetary probes into giant planets : what will we learn ?

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Our four giant planets are both witnesses and actors of the formation of the solar system. Because of their large mass, Jupiter and Saturn played a major role in shaping the entire planetary system. Although Neptune and Uranus appear to have had more secondary roles, they have been, like Jupiter and Saturn, accreting rocks and gas from the solar nebula at different location and time, recording the local thermodynamic conditions at the moment of their formation. By having better constraints on their present composition and structure we can understand better their formation and evolution. This will not only lift the veil on the processes that led to the formation of our solar system, but will also be essential to understand the newly discovered extrasolar planetary systems.

Giant planets grew by accreting three great categories of elements from the protosolar disk: (1) Rocks and iron, i.e. material with high condensation temperatures that were always present in solid form at these locations; (2) Ices, i.e. material with intermediate condensation temperatures, including H_2O, but also probably other molecules such as CH_4, NH_3, H_2S; (3) Gases, i.e. material that has always been in gaseous form, including hydrogen and helium, but also noble gases. Rocks are generally hidden from us in the deep reaches of the atmospheres of these planets, but it is interesting that sulfur should have been brought in at least partly as FeS and the determination of its abundance may be one of the keys to help us determine how much rocks were bought in the giant planets. Noble gases are particularly interesting because they may be bought either with the ices (e.g. as clathrates) or directly with the hydrogen and helium in which case they may tell us about the history of the photoevaporation of the protosolar disk.

So far, Jupiter is the only giant planet on which we have sent a probe (Galileo, in 1995). Thanks to its *in situ* measurement in the well-mixed troposphere of Jupiter, it was able to confirm the expected depletion in helium and neon due to a phase separation in the deep interior of the planet, accurately measure the abundances of CH_4, NH_3 and N_2S, and obtain unexpected enrichments of a factor ~2 over the solar value of Ar, Kr and Xe. Several explanations have been put forward, but similar in situ measurements in Saturn, and to some extent Uranus and Neptune are called for in order to put these theories to the test.

Probes into Saturn, Uranus and Neptune would also provide further unique insight into their internal structure, thermal and chemical evolution. Measurements of helium and neon abundances are essential to determine the presence and extent of helium rainout in the interior, with direct impact on their thermal evolution. Measuring the abundances and isotopic compositions of ice-bearing and even rock-bearing species will provide crucial constraints to understand mixing of elements in the interiors.

In parallel, the discovery and characterization of hundreds of exoplanets provides us with the possibility to study planets from a less detailed but perhaps more general perspective. By coupling a better understanding of giant planets in our solar system to statistical studies of the exoplanet population, we have the possibility to fully theorize planet formation in general, from small rocky planets to the big gas giants. Of course, ultimately, only data obtained from our solar system, in particular in situ measurements in the atmospheres of our giant planets can tell us about our origins.

(170)

THE SCHUMANN RESONANCE: A TOOL FOR THE *IN SITU* AND *REMOTE SENSING* EXPLORATION OF THE DEEP ATMOSPHERE OF GIANT PLANETS

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The Schumann Resonance (SR) phenomena in the Earth surface-ionosphere cavity was predicted by German Physicist Prof. Winfried Otto Schumann who had anticipated its existence in the 1950 (Ref. 1). SR's were detected about 10 years later (Ref. 2). On Earth, they are excited by -mostly vertical- lightning discharge impulsive currents. Under simplifying assumptions that consider the conductivity of the Earth's ionosphere and of its surface to be infinite, the frequencies of the Schumann Resonance are given by the following formula: $f_n = \frac{c}{2\pi R}\sqrt{n(n+1)}$ where *c* is the speed of light, *R* the Earth radius and *n* the harmonic order. This formula gives a fundamental frequency of about 10.6 Hz. When taking into account the medium losses, a more accurate formula is: $f_n \approx \frac{c}{2\pi R}\sqrt{n(n+1)\frac{1-\frac{h}{R}}{\varepsilon_r\left(1-i\frac{\sigma}{\varepsilon_r\varepsilon_0 2\pi f_n}\right)}}$, where *h* is the effective height of the ionosphere, ε_r the relative permittivity and σ the conductivity of the medium assumed uniform, and ε_o the permittivity of vacuum (Ref. 5). This formula gives values close to the measured ones: 7.8 Hz, 14.3 Hz, 20.8 Hz, 27.3 Hz, 33.8 Hz, etc... In addition to the frequency spectrum itself, other characteristics of the SR spectrum are important diagnostic parameters of the cavity. The characteristics of the SR spectrum are affected by several factors, including the day-night ionosphere asymmetry, the magnetic field, ionospheric perturbations and latitudinal variations in the ionosphere profile, in particular at polar latitudes, and the water concentration in the atmosphere. SR's have also been detected by Huygens in Titan's atmosphere. This detection allowed inferring the depth (55-90 km) of the subsurface water-ammonia ocean (the lower boundary of the cavity) below the ice crust, which is assumed non-conductive. On Titan, the SR's are excited by longitudinal ionospheric current systems created by the interaction of Titan's upper atmosphere with Saturn's magnetosphere (Ref. 3 and references therein). It is anticipated that SR's may also be excited by lightning activity in the ionosphere/surface cavity in the atmospheres of other planets, in particular in those of the gas and ice giants (Jupiter, Saturn, Uranus where lightning activity was detected, but detection at Neptune is uncertain, Ref 4.). Recent work (Ref. 5) suggests that the characteristics of the SR's in those atmospheres are influenced by the volatile profile as it governs the electrical characteristics of the cavity. The measurements of the SR's in the giant planet atmospheres is a potential diagnostic tool of the atmosphere profile down to deep depth. While most of the Earth SR observations were made with ground-based measurements, the recent in-orbit observation of the Earth SR's (Ref. 6) allows to envisage that SR's in the giant planets may be detectable not only *in situ* on board an atmospheric probe, but also remotely during a flyby or from orbit. The role of the Earth's magnetic field in the mechanism that allows the SR's to "leak-out" of the Earth cavity is a topic under investigation. It is interesting to note that, so far, no *remote sensing* detection of the SR's on Titan during the numerous Cassini Titan flybys has been reported. This is currently the subject of a special study. This paper provides an overview of the modelling work of the SR's in the atmosphere of the giant planets. The detectability of the SR's by both *in situ* and *remote sensing* techniques will be discussed. The diagnostic powerfulness of the combined approach *in situ*/*remote sensing* will be highlighted. The sensitivity of the SR spectrum characteristics to the volatile profile, especially the water content, will be discussed. Detection techniques, including those for future Titan missions, will be briefly addressed.

Ref 1: W. O. Schumann, « Über die Dämpfung der elektromagnetischen Eigenschwingnugen des Systems Erde – Luft – Ionosphäre » dans *Zeitschrift und Naturforschung*, vol. 7a (1952), p. 250-252; Ref 2: M. Balser et C. Wagner, « Observations of earth-ionosphere cavity resonances », *Nature*, vol. 638 (1960), p. 641 ; Ref. 3 : Béghin et al. Analytic theory of Titan's Schumann resonance: Constraints on ionospheric conductivity and buried water ocean, Icarus 2012 ; Ref 4 : Zarka et al., Study of solar system lightning with LOFAR, Planet. Space Sci. 52 (2004) ; Ref. 5, Simoes et al., ApJ, 2012. Simões et al., Using Schumann resonance measurements for constraining the water abundance on the giant planets- Implication for Solar System formation, Applied Phys. Let., in press (2012); Ref. 6, Simoes et al., Observations of Schumann resonances in the Earth's ionosphere, Geophys Res Lett, 38, L22101, doi:10.1029/2011GL049668.

Session 3: Titan

R. Lorenz: The Titan Mare Explorer (TiME) Discovery Mission (Invited) (31)

The Titan Mare Explorer (TiME) Discovery Mission

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The Titan Mare Explorer (TiME) is a Discovery-class mission to Titan, which has recently completed its Phase-A study. If selected for implementation in July 2012, it will be the first outer solar system Discovery mission, and the first in situ exploration of an extraterrestrial sea.

After the Cassini mission, many aspects of the lakes and seas of Titan will remain unknown or poorly understood, including their detailed composition, physical properties, depth, and shoreline characteristics, all critical to understanding Titan's active methane cycle. Observations of air-sea exchange processes in exotic conditions will inform our fundamental understanding of these important processes on Earth. Titan's seas are also an important astrobiological target: chemical processes on the surface may yield prebiotic molecules impossible to form in gas phase photochemistry. The only way to understand Titan's methane cycle, its climate, and its prebiotic chemistry are through in-situ chemical analysis and observations.

The primary target for the TiME mission is Ligeia Mare (78°N, 250°W), the best-mapped and second-largest sea on Titan with a surface area of ~100,000 km^2. TiME science objectives are: 1) measure the sea chemistry to determine their role as a source and sink of methane and its chemical products, 2) measure the sea depth to help constrain organic inventory, 3) constrain marine processes including sea circulation and the nature of the sea surface, 4) determine sea surface meteorology, and 5) constrain prebiotic chemistry in the sea. TiME's focused instrument package includes a mass spectrometer, a physical properties and meteorology package, and an imaging system. The science objectives of TiME are directly responsive to goals from the 2003 and 2010 Solar System Decadal Surveys, including understanding planetary habitats, through TiME measurements of organics on another planetary object, and understanding the workings of solar systems, through TiME's first in situ measurements of a liquid cycle beyond Earth.

TiME would nominally launch in 2016, with an arrival in 2023. Both Earth and sun barely set below the horizon during the three-month minimum lifetime of the mission, while TiME collects and transmits data as it drifts across the sea. A launch date for TiME before 2019 is essential; launching after that date would result in an arrival during northern winter on Titan, after the sun and Earth have set as seen from Ligeia, making direct to Earth transmission impossible.

TiME would test the Advanced Stirling Radioisotope Generators (ASRGs) in deep space as well as a non-terrestrial atmosphere. Its high heritage instruments, simple surface operations, government-furnished launch and power systems, and relatively benign entry, descent and landing conditions make a sea lander mission to Titan achievable as a Discovery-class mission.

TiME would provide the first in situ exploration of an extraterrestrial sea and the first in situ measurements of an active liquid cycle beyond Earth. By directly sampling the sea liquids, it would aid in understanding the limits of life in the solar system.

P. Beauchamp: The organic aerosols of Titan's atmosphere (183)

The organic aerosols of Titan's atmosphere

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The Cassini mission has discovered large mass negative ions in the upper atmosphere of Titan, Saturn's largest moons (Coates al., 2007). These molecules are supposed to be the building blocs of the aerosols that form the haze surrounding Titan (Waite et al., 2007). These aerosols fall on Titan's surface and may form the sand that constitutes the dunes observed by the radar instrument (Elachi et al., 2006). Solar occultation data provide information on the scattering properties of the haze particles. Bellucci et al. (2009) processed the data obtained during Titan flyby T10 in January 2006 by the Visual and Infrared Mapping Spectrometer (VIMS). The present study extends the data processing to all 10 solar occultations that have been acquired by the VIMS instrument. These observations span a broad range of latitudes from high South latitudes (T10) to high Northern latitudes (T78). The goal is to investigate whether the density of particles varies with latitude as it has been proposed by numerical simulations (Rannou et al., 2006). This analysis should also allow us to constrain the values of the scattering cross-section and that of the density. Our results will be compared to those obtained by the Huygens probe as it descended into Titan's atmosphere in January 2005. The measurements by the Huygens probe suggest that the density of aerosols is almost constant in the troposphere with a peak density arounf 90 km. The peak density is not yet well constrained and values between 5 and 30 cm^{-3} have been proposed (Griffith et al., 2006; Tomasko et al., 2008). As the Cassini mission continues collecting data, a better knowledge of the density of aerosols and its variability with latitude and season will be gained.

Titan is a natural laboratory where organic molecules and organic aerosols are formed. Determining the composition of these organic molecules is key to our understanding of the carbon cycle on Titan Future missions to Titan should have the capabilities of analyzing these different organic compounds. Such information would bring key information on the processes involved in the formation of prebiotic compounds, one of the key ingredient for the formation and evolution of life.

This work has been performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. Government sponsorship acknowledged.

References: Bellucci A. et al. (2009) Icarus ; Coates A.J. et al. (2007) Geophys. Res. Lett; Elachi et al. (2006) Nature ; Griffith C. (2006) Nature ; Rannou et al. (2004) Icarus ; Tomasko M.G. (2008) Planet. Space Sci. ; Waite et al. (2007) Science.

F. Sohl: Scientific rationale of future Titan landing sites (124)

SCIENTIFIC RATIONALE OF FUTURE TITAN LANDING SITES

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Titan is unique due to its similarity to the Earth and terrestrial planets in spite of the satellite's ice-rich bulk composition. The identification of potential landing sites on Titan includes analyses of specific science cases, the definition of candidate sites, and general engineering considerations. Suitable regions for *in situ* science observations are the satellite's atmosphere, surface (solid and liquid) and subsurface. Among the most critical engineering constraints are atmospheric density and composition, ambient temperature, surface hardness/roughness, inclination, subsurface hardness, mechanical uniformity, composition, layering depths and wind-induced seismicity. Furthermore, tidal stresses are expected to induce significant seismic activity comparable to tidally-induced quakes on the Moon and possibly by localized cryovolcanic activity. In the following, we discuss the most promising landing sites, namely polar lake systems, equatorial dune regions, and putative cryovolcanic features, indicating compositional diversity, mobility of surface materials and past cryovolcanic activity, respectively.

The investigation of lakes of hydrocarbons situated above >70° latitude would allow to address the satellite's methanological cycle and the production of organic materials [1]. The shoreline regions of both the northern and southern hemisphere lakes in close contact to liquids are primary targets because: (1) The time-variable chemical and isotopic composition of liquids would help constrain diurnal and seasonal variations in atmospheric photochemistry and precipitation and detect less abundant atmospheric species that are accumulated in the lakes. (2) The chemical and isotopic composition of lake sediments combined with ^{14}C age dating methods would help address both the long-term climate and the short-term seasonal changes. (3) Analysing the sediment record and particles suspended in the lakes would help characterize aerosol precipitation and particle sedimentation as well as aeolian and fluvial erosion. Candidate landing sites like Kraken Mare, Ligeia Mare in the northern and Ontario Lacus in the southern hemisphere would impose challenging engineering requirements in terms of probe release, descent and landing precision. The deployment of a pressure gauge at the bottom of a shallow lake would provide information on the tidal response of the interior by monitoring tidally-induced pressure variations. Another interesting landing site is the Belet dunefield that represents one of the youngest aeolian surface features on Titan. The dune areas [2] best fit engineering requirements and provide a wide range of science goals to be addressed. Owing to the high organic particle content and close relationships to recent erosional and depositional surface processes, they can be indicative of the satellite's habitable potential. Subsurface sounding, using sonar/radar techniques, would also provide important constraints on Titan's stratigraphy and climate history. In the event of a solid landing, radio tracking and seismic investigations would also provide information on the nature of Titan's interior and tectonic activity. Finally the possible cryovolcanic areas, Sotra Facula, Tui Regio and Hotei Regio are considered as candidate landing sites since they combine atmospheric, surface, shallow subsurface and deep interior information [3;4]. In particular, Sotra Facula may represent a sequence of multiple cryovolcanic features surrounded by a series of bright lobate units interpreted as cryomagmatic lava flows (the largest is ~180 km long). Individual peaks and flows are separated by up to 200 km wide dunefield bands and thereby would facilitate taking samples of cryovolcanic and dune materials in the vicinity of the same landing site.

[1] Lorenz, R. et al. 2008. GRL, 35, L02206. [2] Radebaugh, J. et al. 2009. Geomorphology, 121, 122-132. [3] Lopes, R. et al. 2007. Icarus 186, 395–412; [4] Solomonidou, A. et al. (2012). In preparation.

C. Lange: TiNet - A Concept Study for a Titan Geophysical Network (71)

TiNet - A Concept Study for a Titan Geophysical Network

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Titan is a target of high scientific interest due to its similarity with terrestrial planets, despite the satellite's icy bulk composition. Thus, understanding the processes that characterize Titan's atmosphere, surface, and interior provides a possible link to better understanding the origin and evolution of life in the solar system and beyond. One of the main challenges to characterize a complex planetary body such as Titan is to study global properties and processes, most of which cannot be investigated with single point measurements alone, but rather would require a network of several small landed stations, adequately distributed over the whole body. This paper will present the results of a concept study that was recently performed for such a network - further on called TiNet. The study applied the concurrent engineering approach that allows parallel investigation of different aspects of the mission concept (e.g. power, thermal), which are usually investigated sequentially. Based on the initial assumptions and restrictions, e.g. regarding the timeframe in which the mission will be placed or the overall mass budget and general architecture, we will briefly describe the science case together with the respective strawman payload that would be well suited for the chosen landing sites. Furthermore, we will outline the mission architecture and the system baseline including chosen subsystems.

Figure 1: Overall mission architecture as analysed for the TiNet mission (left) and a depiction of the core TiNet elements on the surface of Titan (right)

Figure 1 shows the overall architecture of the TitNet mission. Assuming a launch in the 2030s and an interplantery cruise with several swingbys at Earth and Venus, the network would be deployed after arrival in a polar orbit around Titan. Three entry probes would enter the Titan atmosphere at three different locations to allow a global distribution of nodes and access to a diverse and interesting set of landing sites. Each of these entry probes itself consists of several sub-elements: (i) the Entry-Descent and Landing (EDL) System, (ii) the central station or hub and (iii) three remote stations. Following entry into the atmosphere and during descent of the probe, the remote stations shall be deployed from the hub and shall land in an adequate distance to allow a local distribution on the surface of Titan. Using this approach would facilitate to perform unique science on the surface. In addition, the architecture and systems would allow for substantial flexibility in terms of instrument exchange and robustness to cope with harsh environmental conditions at different landing sites.

Orbitrap Mass Analyser: a Tool for Titan Complex Molecular Content Exploration

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The Cassini-Huygens measurements show the existence of very large molecular structures in Titan's atmosphere as well as on its surface in the form of dunes deposits or lakes, at levels that can be sampled directly by spacecraft in the upper atmosphere/ionosphere, balloon, or lander. We do not know the nature and structure of most of these molecules, but they are organic, i.e. containing C, H, N, and potentially O. The presence of cyclic molecules, amines, hydrocarbons, and oxygen suggests that molecules similar to biological building blocks on Earth could be formed. Titan is therefore a unique opportunity to study a phase of pre-biotic chemistry, occurring right now. The Cassini-Huygens instruments already showed that their analytical performances are insufficient to characterize the very complex medium they probe. It is therefore necessary to develop new instrumentation to improve the description of the molecular structures that are produced.

Mass spectrometry, by its ability to analyse and quantify species from almost any type of sample (provided the appropriate sampling and ionizing method is used) is an excellent tool to study the complex mixtures expected on Titan (1). The ability then to assign molecular formula to masses depends on the resolution of the mass analyser; it requests higher resolution mass analysers than those of Cassini/ Huygens. As already stated in the TSSM study, to go back to Titan, a high-resolution mass spectrometer will be mandatory. We develop the concept of mass analyser for space applications that is lightweight and provides ultrahigh resolving power capabilities ($M/\Delta M$ beyond 10^5 up to m/z 400): the Orbitrap.

The Orbitrap mass analyser concept was demonstrated in 2000 (2). Since 2009, CNES has funded an R&T program in order to study the space applications of the concept. A consortium of 4 laboratories located in France: LATMOS, LPC2E, LISA, coordinated by IPAG in collaboration with Thermoelectron company was organized and a first prototype is now running at LPC2E, Orléans. We will describe the concept, its performances, and the required steps to develop an orbitrap-based high-resolution mass spectrometer that would meet the required performances for a future Titan mission. Implications of its use on an orbiter, a balloon or a lander will be discussed.

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(1) P.Pernot et al. "tholinomics – chemical analysis of nitrogen-rich polymers" Anal. Chem. (2010) 82,4 1371-1380
(2) A. Makarov, "Electrostatic Axially Harmonic Orbital Trapping: A High-Performance Technique of Mass Analysis", Anal. Chem., (2000) 72, 1156-1162.

Modeling and Validation of CN Violet Radiation Relevant to Titan Entry

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Radiation during Titan entry is important at lower speeds (around 5 – 6 km/s) compared to other planetary entries due to the super-equilibrium formation of CN in the shock layer (concentrations of approximately 50% higher than equilibrium), which is a highly radiative species. However, the modeling associated with this strong radiator suffers from at least two difficulties: a) the kinetics of CN excited state populations are not well quantified, and b) given accurate CN excited states, there is disagreement in the literature about appropriate radiation transport models. The radiation emitted from these highly nonequilibrium conditions has previously been simulated using Boltzmann assumptions to calculate the distributions of species. The results from these analyses showed a substantial over-prediction of radiation compared to experiment. This led to the development of collisional-radiative models. These models include finite-rate chemistry to simulate the excitation and de-excitation of the electronic energy levels of CN molecule and the subsequent radiation emitted during entry into the Titan atmosphere. Despite some previous analysis suggesting that the absolute levels of radiation have been modeled correctly, comparisons with shock tube experiments have shown that CR models still over-estimate the level of radiation by approximately a factor of 4 – 12, depending on the atmospheric entry condition, see Figure 1.

Experiments have been conducted at The University of Queensland in the X2 high enthalpy shock tube to measure the nonequilibrium radiation in Titan-like atmospheres. These experiments were performed across a large pressure, shock tube and composition range with the aim of being used for code and theoretical model validation. Due to the large set of experimental data, the focus of this paper will be to use these results to: 1) validate the rate for the excitation reaction: CN(X) + M = CN(B) + M, 2) model the decay rate from the non-equilibrium peak to equilibrium level, 3) introduce a new parameter independent of absolute calibration and experimental set-up indicating the level of non-equilibrium and 4) using this parameter to determine a new CN excitation rate based on the X2 data. Initial results indicate that we can reduce the radiative intensity for Titan entry by a factor of approximately 20 compared to Boltzmann predictions.

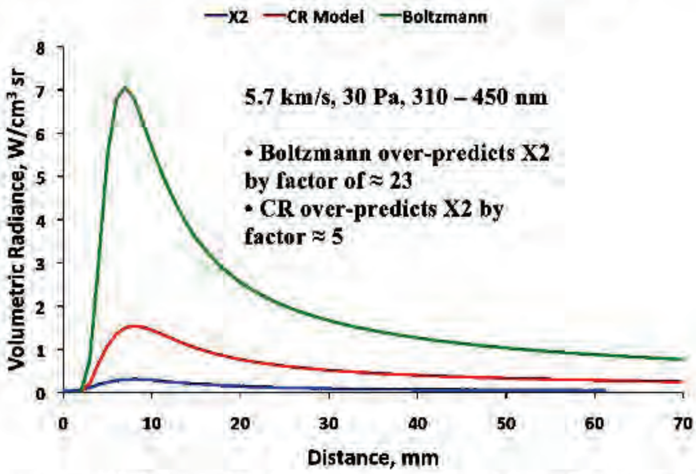

Figure 1. Comparison of X2 data with results using a CR model and Boltzmann distribution

TITAN MONTGOLFIERE BALLOON ANALYSIS AND DESIGN USING COMPUTATIONAL FLUID DYNAMICS SIMULATIONS

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A Montgolfiere, or hot air balloon, is an attractive mobile platform for carrying scientific instruments on a wide-ranging exploration of Titan's lower atmosphere and surface regions. The key to successful implementation of the concept is an accurate prediction of buoyancy across the wide range of flight conditions expected on a long duration mission in the Titan environment. This paper reports on recent results from modeling thermo-fluid behavior of a Titan Montgolfiere using computational fluid dynamics (CFD) simulations. Many CFD simulations were performed, grouped into four categories that explored different aspects of the overall problem. First, Reynolds-averaged Navier-Stokes (RANS) techniques were used to model 1 meter diameter single and double wall balloons that were tested at cryogenic temperatures (90K) on Earth. Good agreement was obtained between the measured and simulated buoyancy for both balloons. Second, RANS models were used to simulate full scale (10 meter) double-wall balloon designs either as closed spheres or with realistic geometrical features such as a teardrop shape and an inlet hole at the bottom of the balloon. Although there were small differences between the closed sphere and realistic geometry computations, both sets of results showed that the double-wall design was less effective at increasing buoyancy than estimates based on engineering heat transfer correlations for concentric heated spheres held at uniform temperatures. This discrepancy led to the third group of simulations that focused on the thermo-fluid behavior of an idealized gap using direct and large-eddy simulation techniques that directly resolve the unsteady, turbulent convective flows for a Rayleigh number range of $10^4 < Ra < 10^9$. Comparing these results to RANS simulations and correlations suggests that the engineering correlations do not provide accurate heat transfer estimates for the turbulent flow in thinner gaps under turbulent flow conditions. The fourth set of CFD simulations quantified the change in buoyancy performance due to forced external convection, modeling those flight conditions for a balloon with changing altitude. The paper concludes with a short parametric assessment that maps out the payload mass versus float altitude versus balloon size design space for full scale Titan Montgolfiere double-walled balloons using the heat transfer performance quantified by the recent CFD results. The basic conclusion is that the balloon diameter must grow by 10% to 20% to compensate for the poorer buoyancy performance indicated by the recent CFD simulations as compared to previous estimates based on correlations.

Lessons for Titan balloons from recent terrestrial experience

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Ever since the Cassini spacecraft started orbiting in the Saturn system in 2004 and particularly following the descendent of the Huygens probe to the surface of Titan, there has been ever-growing interest in Titan in general and exploring it with balloons in particular. Titan offers both outstanding science objectives and exceptionally good conditions [much better than Earth] for balloon operations.

The period in the 1990's culminating in the first successful circumnavigation of the Earth by balloon in 1999 saw an unparalleled expenditure on balloon development. Between $50 million and $100 million dollars was spent on technical development in this period in what became a significant technological race to be first around the world. The two successful flights and indeed nearly all attempts used Roziers, combined helium and hot air balloons. Understanding heat transfer was crucial to these designs just as it currently is for Titan balloons. They also used multiple fabric layers to provide insulation. This too appears critical for any Titan balloon. The success of these designs is self-apparent. Before "The Race" began, the longest flight by a manned balloon was six days. "Breitling", first to fly right around the world, flew for twenty days.

One of the authors [Cameron] designed both the Breitling balloon and the balloon used by Steve Fossett for a subsequent successful flight around the world. In addition to the main authors, a number of leading participants in attempts to fly around the world will contribute to this paper. So the paper will have access to extensive and detailed technical information.

This paper will extract as much as possible of what was learned from terrestrial balloon experience during this period: this should prove of considerable value to the design of Titan balloons.

Buoyancy Estimation of a Titan Aerostat

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The dense atmosphere of Titan is an excellent medium to permit aerostatic platforms to fly repeated circumnavigations in order to map that world's remarkably varied surface features. One of most promising platform types is a Montgolfière using a Radioisotope-Thermoelectric Generator (RTG) to warm the interior gas, as well as providing necessary onboard electrical power. However, previous work advocated a double-wall envelope in order to reduce the heat transfer rate, and thereby achieve the required buoyancy for a realistic size.

In this paper we will propose that a single-wall envelope could be used, provided just the upper envelope region is effectively insulated. We will also show that is not necessary to fit a crown valve, since the convective flow of the RTG may be effectively modulated below the envelope.

To justify our claims, we will report the essential outcomes of a set of room–temperature laboratory experiments involving electrically-heated, single-wall, natural-shape aerostats. The resulting measurements of buoyant lift are found to closely match an analytical model employing established heat transfer correlations. The model is extrapolated to cryogenic conditions representative of Titan's lower troposphere and the predicted buoyancy is found to be approximately 30% higher than previously estimated. To account for the difference with previous estimates, it is suggested that internal free convection heat transfer rate is lower than previously assumed. Furthermore, based on drizzle experiments performed, we will present estimates of the predicted heaviness of an aerostat when exposed to Titan rain. We find that in fact the weight penalty is rather modest.

Whilst there is a rich history of long-distance hot-air ballooning on Earth, much of this heritage is based around visceral experience and anecdotal evidence. The experiments reported here represent a step to providing a secure quantitative foundation - to support realistic design efforts - that could lead to the efficient, near-future exploration of Titan. We believe that such an aerostatic exploration venture is well within engineering capability, and yet it would capture the interest and imagination of millions of people, young and old.

A Simple Entry, Descent, and Floating System for Planetary Ballooning

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Balloons are attractive planetary exploration systems in that they can both observe a larger area than rovers and observe the surface at a higher resolution than orbiters. Balloons can also fly for longer stretches of time and distance than aircraft. In particular, balloons are appropriate for explorations of planets or moons with a dense atmosphere, such as Venus or Titan. However, while balloons can fly stably once they have a sufficient volume, one hindrance to realizing a planetary balloon is to ensure the reliability of its automatic deployment and inflation. Planetary balloons generally require the performance of some critical operations—namely, multistage parachute deployments/separations, heat shield jettison, and aerial balloon deployment/inflation—during atmospheric entry, as was the case in the VEGA mission.

Therefore, in this study, a planetary balloon system is considered that is inflated in orbit around a planet or moon before the atmospheric entry. The balloon is inflated using He gas stored in the orbiter and then separated from the orbiter. The inflated balloon is decelerated by aerodynamic drag and then simply floats at a balanced altitude or makes a soft landing owing to its buoyancy, without the need for the abovementioned critical operations during atmospheric entry. The atmospheric entry probe is the simplest entry, descent, and floating (EDF) system considered to date in that no critical operation is required during atmospheric entry. The system has functions of a heat shield, a decelerator, and a balloon in a single configuration. The balloon system has the following advantages: (1) the abovementioned critical operations are not required during atmospheric entry; (2) the entry probe does not need to carry a He gas tank to a floating altitude for balloon inflation; (3) because the inflated balloon has a low ballistic coefficient, the balloon can deorbit by using the aerodynamic drag rather than by using an additional deceleration or trajectory maneuver; (4) because of the low ballistic coefficient, the peak aerodynamic heating during the atmospheric entry will reduce, and thus, contamination of the atmosphere due to ablation would be prevented; and (5) because the entry probe can decelerate at a high altitude owing to the low ballistic coefficient, observations can be performed over a large altitude range during the descent.

In this study, the feasibility of the atmospheric entry balloon for Titan and Venus is investigated by performing trajectory calculations for various balloon diameters, payload masses, and floating altitudes. The balloon is assumed to have a simple spherical shape. Therefore, the aerodynamic characteristics of the balloon are attitude-independent and easy to estimate. The feasibility study focuses on (1) the tensile strength of the balloon envelope against internal pressure, (2) heat resistance of the balloon envelope against aerodynamic heating, (3) structural strength of the balloon against dynamic pressure and inertial force generated because of the deceleration of the balloon, and (4) flight characteristics required for stable floating of the balloon at a designated altitude. The results show that relatively small balloons can meet the abovementioned four minimum requirements. Although a single small balloon cannot carry a heavy payload, many small balloons can be used for simple distributed explorations. In addition to the feasibility study, a drop test of the balloon system from a stratospheric balloon is proposed to demonstrate the flight characteristics and the stable floating at a designed altitude.

Session 4: Venus

S. Limaye: Exploring Venus With Balloons - Science Objectives and Recent Technical Advances

EXPLORING VENUS WITH BALLOONS - SCIENCE OBJECTIVES AND RECENT TECHNICAL ADVANCES

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Following the trailblazing flights of the 1985 twin Soviet VEGA balloons, missions to fly in the skies of Venus have been recommended by the 2011 Decadal Study of the National Reasearch Council and have been proposed to NASA's Discovery and ESA's Cosmic Visions programs. Such missions will answer fundamental science issues highlighted in a variety of high-level NASA-authorized science documents in recent years, including the 2011 and 2003 Decadal Surveys, various NASA roadmaps, and recommendations coming out of the Venus Exploration Analysis Group (VEXAG). Such missions would in particular address key questions of Venus's origin, evolution, and current state, including detailed measurements of (1) trace gases associated with Venus's active photo- and thermo-chemistry and (2) measurements of vertical motions and local temperature which characterize convective and wave processes.

One mission proposed for NASA's Discovery Program is VALOR, the Venus Atmospheric Long-Duration Observatory for in-situ Research. Floating in Venus's rapid windstream near an altitude of 55 km, VALOR would circle the globe five times over a twenty-eight day period, sampling *in-situ* numerous key molecular species including noble gases, their isotopes, and key chemicals diagnostic of Venus' sulfur-based chemical cycle. VALOR would test a variety of scenarios for the origin, formation, and evolution of Venus by sampling all the noble gases and their isotopes, especially the heaviest elements never reliably measured previously, xenon and krypton. Drifting over a wide range of latitudes and all times-of-day, VALOR would accurately measure (1) vertical and horizontal motions within Venus's convective middle cloud layer, (2) the power and frequency of local lightning generated by these clouds, and (3) both the cloud particles themselves and their parent molecules, as it studies Venus' dynamic circulation and meteorolical processes. Tracked both by an array of Earth-based radio telescopes, and on the planet's backside by the carrier spacecraft, the zonal, meridional, and vertical winds would be measured with unprecedented precision. Altogether, such measurements would help in developing our fundamental understanding of (1) the circulation of Venus, including the role of waves in powering the planet's poorly-understood super-rotation, (2) the nature of Venus's sulfur cycle, key to Venus's current climate, and (3) how Earth's neighbor formed and evolved over the aeons.

The VALOR balloon has been under development for a number of years, including the successful fabrication and testing of two 5.5 m diameter prototypes. Recent work reported here assessed the susceptibility of the balloon material to folding- and abrasion-induced pinhole creation and the attendant effect on balloon lifetime due to helium loss and sulfuric acid intrusion.

C. Wilson: The European Venus Explorer (EVE) 2010 mission proposal

The European Venus Explorer (EVE) 2010 mission proposal

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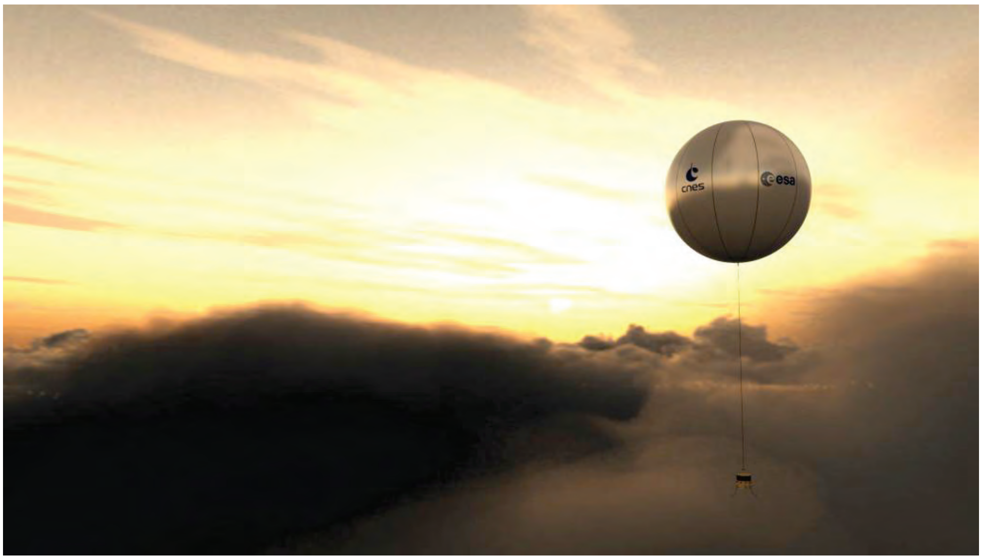
The European Venus Explorer (EVE) mission described here was proposed in December 2010 to ESA as an `M-class' mission under the Cosmic Vision programme. It consists of a single balloon platform floating in the middle of the main convective cloud layer of Venus at an altitude of 55 km, where temperatures and pressures are benign (~25°C and ~0.5 bar). The balloon float lifetime would be at least 10 Earth days, long enough to guarantee at least one full circumnavigation of the planet. This offers an ideal platform for the two main science goals of the mission: study of the current climate through detailed characterization of cloud-level atmosphere, and investigation of the formation and evolution of Venus, through careful measurement of noble gas isotopic abundances. These investigations would provide key data for comparative planetology of terrestrial planets in our solar system and beyond.

The 15kg scientific payload includes a mas spectrometer devoted to isotopic ratio and noble gas measurement, equipped with getters and cryotraps to remove the dominant atmospheric species permitting detection of trace gas species. The chemistry payload includes a gas chromatograph, dynamic mass spectrometer and tunable laser absorption spectrometer for the chemical analysis of atmosphere and aerosol composition, and a nephelometer and X-ray fluorescence spectrometer for the microphysical and elemental characterization of cloud droplets. Cloud-level radiative-dynamic feedbacks will be investigated using a meteorology suite (pressure, temperature, vertical wind) and radiometer. Finally, an electrical field instrument measures the AC and DC components of electrical field, providing information on the electrical properties of atmosphere, ionosphere and subsurface.

Critical factors for the success of a Venus balloon mission include mass, datarate, and power. The trade-offs evaluated and solutions reached for EVE will be presented.



T. Balint

Development of a Venus Entry System for the Surface and Atmospheric Geochemical Explorer

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Renewed interest in Venusian science is driving the development of new mission architectures to explore the climate, geological, and the historical context of our sister planet in terrestrial planet formation. The evidence of recent volcanism, geological discoveries of tesserae, and even Earth-based climate science, has once again brought Venus to the forefront of planetary science. Venus's runaway green house effect continues to mystify the science community and draw parallels to climate change processes on Earth. As a result, a variety of potential planetary probes to Venus are currently being investigated by NASA, with a range of capabilities extending to surface accessibility.

Due to the dense atmosphere, high temperature, and thick cloud layer, remote sensing of the surface of Venus is challenging, limiting the data that can be obtained. Therefore a surface science mission that enables in-situ geological, mineralogical, and climatological measurements of the planet is of high value to the science community. In addition the Venus Express imaging of what could be recent volcanic flows provides scientific context and definitive landing site requirements for a science-focused mission. To enable such a mission an entry, descent, and landing (EDL) system was designed for a near-term mission that addresses the unique challenges of a Venus entry in terms of entry velocity, deceleration, and surface environment, while still relying on heritage technologies and processes.

The Surface Atmosphere and Geochemical Explorer is a landed mission concept that would descend ballistically through the atmosphere of Venus inside a blunt body aeroshell, placing a lander on the surface for a three-hour mission duration. The lander would be equipped with descent and post landing cameras, sensors to measure atmospheric temperature, pressure, and wind, a tunable laser spectrometer and neutral mass spectrometer to measure isotopic ratios and gas composition, and a neutron-activated gamma ray spectrometer and a Raman/LIBS spectrometer to measure surface composition

A Venus EDL architecture will be presented including entry system and landing site requirements, a trade space of three degree-of-freedom entry-trajectory simulations, and overall system sizing. The prototype EDL system would use a 45-deg sphere cone carbon phenolic heat shield, pilot-deployed conical ribbon parachute system, rigid aerodynamic decelerator for terminal descent, pressure vessel lander body, and a crushable landing attenuation device. The key elements to be presented will include computational analyses of the aerothermal environment and loads, and thermal protection system (TPS), predictions of parachute performance, as well as the aerodynamic performance of and terminal descent system. System architecture trades will also be discussed in terms of optimization of structural mass, TPS mass, landing site accessibility, and peak heating.

Parachute Development for Venus Missions

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Parachutes are a proven, mass-efficient system for entry, descent, and landing (EDL), both here on Earth, and on other bodies such as Mars and Venus. This paper will focus on development considerations of parachutes to be used for Venus missions. For the anticipated Venus mission masses, parachute reference diameters (D_0) between 6 ft for a small probe and 40 ft for a large lander will be considered.

The atmosphere of Venus presents both opportunities and challenges for parachute development. The main challenge is obviously the highly corrosive sulfuric acid laden atmosphere. Modern fibers have the ability to handle these environments, at a substantial weight savings over pervious Venus parachute systems. Comparisons between the heritage ribless guide surface (RGS) and the variable porosity conical ribbon (VPCR) parachutes for the Venusian atmosphere will be discussed.

Due to relative similarity in atmospheric density at likely parachute deployment altitudes between Earth and Venus, parachute development for Venusian missions enjoys an advantage in the ability to closely match mission deployment conditions during validation testing. Techniques for parachute testing of parachutes for Venus missions will be discussed, as well as the benefits and compromises each technique presents.

Technologies for a Long Duration Lander on the Surface of Venus

Douglas S. Mehoke, Ralph D. Lorenz, Stuart W. Hill

The technologies needed for a long duration stay on the surface of Venus are discussed. Due to the extreme environment on the surface, there is not one technology that will enable all potential missions, but rather there are different technologies that address specific types of missions. Three basic approaches are discussed in the paper. The first approach uses a hybrid system consisting of a cooled core that accommodates the lander avionics and RF functions using standard electronics. This system includes the external sensors and apertures that support the mission payload defined in the Venus Flagship study. This approach has been worked on at NASA Glenn Research Center (GRC) [Dyson and Bruder] for the past few years and a technology path has been developed around a Stirling duplex system providing over a thousand watts of payload cooling. The bulk of the paper describes a second approach that uses a scaled down version of the above system, with a limited scientific payload, that drastically reduces the heat leak into the cooled area. This system still uses a NASA GRC duplex Stirling system, but the lower power requirements limit the technology advances needed to make the system viable. This change dramatically lowers the technology development and overall cost of the system. One final approach is summarized that eliminates the hybrid system altogether in favor of a high-temperature system where all the components operate in the ambient Venus environment. This approach uses advances in high temperature circuits to develop simple sensors and the related collection and transmitter functions. The paper discusses the needed technologies and related timelines for the different approaches.

E. Venkatapathy: A Game Changing Approach to Venus In-Situ Science Missions Using Adaptive Deployable Entry and Placement Technology (Invited)

A Game Changing Approach to Venus In-Situ Science Missions Using Adaptive Deployable Entry and Placement Technology

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The harsh conditions (9.3 MPa pressure and 735 K temperature) at the surface of Venus present a considerable challenge for prolonged *in situ* science. Furthermore, missions to Venus also face challenges in the entry segment of the Entry, Descent and Landing (EDL) sequence because the combination of high entry speeds and a dense atmosphere make for severe heating environments, and large deceleration loads. For example, the small probe of the Pioneer-Venus family of probes experienced a deceleration load of roughly 450 g's; the largest probe, however, experienced a deceleration load of roughly 100 g's. This experience is no different from that of the Venera program of Russia. Even if one were to fly balloon missions, which perform *in situ* atmospheric science, the extreme thermal environment and structural loads (due to high deceleration) require the use of heavy structure and ablative thermal protection systems with high-density material. The robustness requirements placed on the traditional rigid aeroshells employed in Venus missions reduces the mass of the science payload (while increasing its risk), and hence a much reduced return on investment in the missions.

The entry system community is actively studying ways to address issue of thermal environments through the use of thermal protection systems (TPS) with improved mass efficiency. However, a traditional rigid aeroshell configuration forms the basis for the entry system. The rigid aeroshell conifguration has been used successfully and safely for entry into atmospheres of various planets and/or moons, from Venus to Jupiter to Titan.

At the last International Planetary Probe Workshop (IPPW8), a different approach, referred to as Low Ballistic Coefficient Aeroshell Technology (LBCAT), was presented. Unlike the rigid aeroshell, referred to as High Ballistic Coefficient Aeroshell Technology (HBCAT), which has a fixed outer shell with a robust TPS, the LBCAT aeroshell *deploys*

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S. Limaye: Sampling the Unexplored Regions of Venus (Invited)

Sampling the Unexplored Regions of Venus

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In the five decades of planetary exploration that began with the successful fly-by of Venus by Mariner 2 on 14 December 1962, properties of the Venus atmosphere have been measured by Venera (4 through 14 during 1967 - 1982), Pioneer Venus (North, Day, Night and Large on 4 December 1978), VeGa 1 VeGa 2 entry probes (11 June 1985) and by two VeGa balloons (11-15 June 1985). Since then proposals have been developed for probing the atmosphere using balloons (NASA Discovery and ESA Cosmic Vision) and entry probes (NASA Discovery and New Frontiers) for exploring the surface and atmospheric measurements. All of these observations have been below 62 km, except for temperature and density data derived during ballistic entry from Pioneer Venus probes (between 85-62 km).

Remote sensing observations indicate that the cloud layer of Venus extends far above 62 km and that the upper levels contain a mix of smaller haze particles with a radius of about 0.1μ. This haze extends to altitudes of 75 km and perhaps higher. The cloud layer includes an ultraviolet absorber whose properties are not known. More importantly, the identity of the ultraviolet absorber in the clouds of Venus has not yet been confirmed although several chemical species have been proposed. Observations made in reflected sunlight suggest that the ultraviolet absorber may be more abundant in the upper regions of the global cloud cover, above 62 km. Direct sampling of the levels above 62 km is therefore highly desired to establish the identity of the ultraviolet absorber and to measure the particulate properties and abundance in the 60-80 km region of the atmosphere. All of the previous measurements in the atmosphere of Venus have begun at about 62 km altitude above the mean surface and the two VeGa balloons sampled the Venus atmosphere for about two days at an altitude of ~ 54 km.

Direct sampling this region of Venus has not been possible so far, but recent technological developments suggest that in the future such observations can be obtained from Unmanned Aerial Vehicles (UAVs) at 60-70 km level on Venus. UAVs and light weight sensors are being increasingly used for atmospheric measurements on Earth and that experience is promising enough to warrant a study for potential use for Venus.

Similarly, high altitude balloons are used routinely for long duration observations at ~ 30-40 km on Earth, but the feasibility of use of such balloons for Venus at comparable pressures and temperatures has not yet been looked into and may prove to be useful for in-situ data collection and dynamical observations to confirm the puzzling highly dynamic circulation from Doppler measurements suggested by observations from Earth based telescopes.

Venus Atmospheric Platform Options Reconsidered

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In 2010, the European Venus Explorer (EVE) mission proposal advocated the use of a near-spherical helium-filled super-pressure balloon (similar to VEGA 1 & 2) in order to sample the Venusian atmosphere at a fixed altitude of about 55 km.

One criticism of this platform option is that, although the balloon would experience vertical gusting, the vertical extent of the atmospheric sample would be limited. Ideally, a platform that could traverse through the cloud layers from about 40-60 km (on demand), would provide a better means of atmospheric sampling, resulting in greater scientific gain.

Another problem with using a helium-filled pressure super-pressure balloon is that it requires a relatively heavy compressed helium gas storage tank, resulting in substantially increased overall system mass (and therefore mission cost), or significantly reduced payload capability.

In this paper, several different platform options will be reconsidered, including the concept of using a phase change balloon that oscillates in altitude[1], an infra-red Montgolfière[2] that uses planet-reflected radiation to heat its interior and thereby achieve buoyancy, and finally the "Vetrolet" (or "Wind Flyer") system, utilizing wind shear, as the proposed Venera-D mission[3].

It is concluded that each of these alternative systems could offer significant advantages over super-pressure balloons, and consequently they all deserve further in-depth study.

[1] Dorrington, G.E. (2010) Venus Atmospheric Platform Options Revisited, *Adv. Space Research*, 46, 310-326, 2010.

[2] Malatere, P. (1993) Long-Duration Balloon Flights in the Middle Stratosphere, Adv. Space Research,
13, 107-114.

[3] Vorontsov, V.A. *et al*. (2011) Prospective Spacecraft for Venus Research: Venera-D Research, *Space System Research*, 45 (7) 710-744.

Session 5: Mars

F. Ferri: ExoMars Atmospheric Mars Entry and Landing Investigations and Analysis (AMELIA) (Invited)

ExoMars Atmospheric Mars Entry and Landing Investigations and Analysis (AMELIA)

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The entry, descent and landing of *ExoMars* Descent Module (EDM) offer a rare (once-per-mission) opportunity to perform an *in situ* investigation of the martian environment over a wide altitude range. The ExoMars AMELIA team seeks to exploit the Entry Descent and Landing System (EDLS) engineering measurements for scientific investigations of Mars' atmosphere and surface.

From the measurements recorded during entry and descent, using similar methods and analysis employed on previous entry probe missions (e.g. ESA Huygens at Titan, NASA Mars PathFinder, Mars Exploration Rovers and Phoenix) we will retrieve an atmospheric vertical profile along the entry and descent trajectory. Within the AMELIA team, different approaches, algorithms and methods will be used for simulation and reconstruction of the EDM trajectory and attitude during the entry and descent phases in order to retrieve and validate the most accurate atmospheric profile.

A near-real-time reconstruction of the trajectory will be performed using the radio communication link between the EDM and the radio receiver on board the orbiter and by the carrier signal detection by ground telescopes. Atmospheric vertical profiles of density, pressure and temperature, will be derived by several methods including: direct inversion from deceleration measurements; by matching an atmospheric standard model with Extended Kalman filtering (EKF) of a 6 DoF EDM dynamic model; and from hypersonic dynamic pressure data recorded during entry.

The dynamical behaviour of the EDM during the descent under parachute will be modeled, simulated and reconstructed using different data, methods and data assimilation (e.g. IMU, radio link, radar, imaging and auxiliary data). Wind profile along the entry probe path will be retrieved by using the Doppler shift in the radio link between the Descent Module and a radio receiver and by modeling the dynamic response of the pendulum system composed by the EDM and the parachute line.

In order to study the atmospheric dust load, AMELIA aims tentatively to investigate aerosols from frontshield ablation and by the analysis of the EDM back-cover sun sensor data to derive opacity as function of altitude during the period of operation

Scientific analysis of the landing measurements will be aimed at the determination of the landing site context (e.g. surface mechanical characteristics, geomorphology, etc.), its characterization and assessment also in combination with remote sensing imaging.

ExoMars 2016 will provide the opportunity for new direct *in situ* measurements during the martian statistical dust storm season. These data will contribute to exploring an altitude range and a vertical resolution not covered by remote sensing observations from an orbiter, providing a surface and atmosphere "ground truth" for remote sensing observations and imposing important constraints on the validation of Mars atmosphere models.

The experience and lessons learned in the framework of the Huygens project, Mars probes, and expertise in Mars observations and modelling will be put in perspective for the ExoMars Entry, Descent and Landing (EDL) science experiment.

ExoMars EDM Mission and Development Status

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The ExoMars Programme is an international cooperation to explore Mars and will make use of the 2016 and 2018 launch opportunities. The mission planned for a launch in 2016 contains a science and data relay orbiter, the so called Trace Gas Orbiter (TGO), that also carries a Descent Module containing a surface platform to Mars. This paper will concentrate on an update of the status of the Entry Descent and Landing Demonstrator Module (EDM). The EDM fulfills several major ExoMars objectives, namely a demonstration of key technologies required to safely land a payload on the surface of Mars as well as operate a science payload for an extended period of time on the Mars surface allowing to provide some significant scientific data.

The science payloads will include the European DREAMS sensor package and several sensors provided by international partners. Since the beginning of this year the science payloads were complemented by new instruments and sensors from international partners enlarging the scope and detail of the characterization of the entry descent and landing phase as well as the on ground scientific measurements. The overall system performance of the landing platform is also improved with respect to surface lifetime of up to several months, improving the scientific output remarkably.

The key technologies to be demonstrated also in light of future planned missions are Heat Shield, Parachute System, Doppler Radar System, Liquid Propulsion System for attitude control and final braking, Crushable structure to attenuate the landing impact loads at touch down on Mars.

These technologies and scientific payloads will be embarked into the EDM, a 600 kg 2.4 m diameter vehicle. In addition to the science payload and in order to maximize the lessons learnt from this demonstration mission, the EDM is equipped with inflight measurement sensors that will allow a reconstruction of the trajectory and an assessment of the performance of the EDL subsystems.

The paper will provide an overview of the EDM mission and design status, presenting also the latest changes to the science payloads resulting from the new international cooperation foreseen. The paper will describe the development status and the latest test activities performed for the various Entry Descent and Landing technologies as well as an outlook of the coming planned activities.

Status of the Mars Entry Atmospheric Data System (MEADS) Hardware and Data Reconstruction Effort

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The Mars Science Laboratory (MSL) Entry, Descent and Landing Instrumentation (MEDLI) hardware was launched on its way to Mars in November 2011. A team of engineers on the ground continues to make preparations for data return in August 2012. This work will present the status of the Mars Entry Atmospheric Data System (MEADS) portion of the MEDLI system. Hardware health status and readings of the zero pressure were obtained during a power-on in March 2012, which are critical for accurate measurements during entry. The reconstruction team has continued to work with hardware, software, and operations engineers to refine the tones and real-time data returned during entry. Most importantly, extensive wind tunnel and ballistic range testing, as well as computational fluid dynamics and simulation work, has been accomplished in the past year to ensure the returned data is understood and can be used to improve future entry designs. The current simulation results show that the MEADS reconstruction approach provides excellent observability and determination of faulty readings or unanticipated vehicle characteristics. Other key results of the testing, analysis, and simulation efforts, and future plans, will be presented.

Status of the MEDLI Integrated Sensor Plug (MISP) Hardware and Data Reconstruction Effort

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The Mars Science Laboratory (MSL) Entry, Descent and Landing Instrumentation (MEDLI) hardware was launched on its way to Mars in November 2011. A team of engineers on the ground continues to make preparations for data return in August 2012. This work will present the status of the MEDLI Integrated Sensor Plug (MISP) portion of the MEDLI system. Hardware health status and readings of the cruise phase heatshield temperatures were obtained during a power-on in March 2012. The reconstruction team has continued to refine the tones and real-time data returned during entry. Most importantly, arc jet testing of the MISP plugs and material property characterization, as well as both computational fluid dynamics and ablator simulations are ongoing to ensure the returned data can be used to improve future entry designs.

The MISP reconstruction approach involves reconstructing the ablator response for each plug, then combining the series of instrumented plugs to assess overall heatshield performance and aerothermal environments. This work will present details of the ground testing, simulation efforts, and anticipated post-flight analysis procedure.

IPPW-9 Mission Architecture and System Design of a Mars Precision Lander

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A Mars Precision Lander mission has been studied for ESA as part of Mars Sample Return (MSR). The overall mission has been designed to deliver a payload of ~100kg onto the surface of Mars with a landing precision of 10 km (3σ), with a goal of 7.5km (3σ). This landing precision which is an order of magnitude better than current ESA Mars missions is necessary to deliver a Sample Fetch Rover in close proximity to other elements of a potential MSR Mission. A precise and safe landing is non-trivial, and requires precise navigation and targeting during the Mars approach phase, a highly accurate guided entry and a powered descent phase capable of surface hazard avoidance.

Multiple mission architecture options were analysed in detail, particularly for the critical terminal descent and landing phase where options included airbags, crushable structures and landing legs. After a full trade-off analysis, a 'DropShip' design similar to NASA's SkyCrane approach was selected for the baseline. This concept eliminates the mass of any landing and egress systems, landing the rover directly on its wheels. A DropShip has the added benefit of avoiding the thruster plume and back-pressure issues associated with Viking-type landers.

The Mars Precision Lander mission architecture comprises a carrier and a guided entry module, with the DropShip powered descent module and attached rover enclosed by the guided entry module aeroshell. The composite has a total wet mass of 1408 kg and would launch in Autumn 2023 from Kourou on a Soyuz-Fregat launch vehicle. A direct escape launch would be performed, with an Earth fly-by included to increase the useful mass delivered to Mars. After a transfer of 1.9 years, the composite would approach Mars and the guided entry module would separate from the carrier to directly enter the Mars atmosphere.

The guided entry phase uses thrusters scarfed through the backshell to correct the trajectory and steer towards the landing site. A Disk-Gap-Band parachute would be deployed at a nominal altitude of 10km, followed closely by frontshield separation and the DropShip separation from the backshell between 1.1 and 1.5km. The DropShip then fires its thrusters for the terminal descent braking and hazard avoidance phase. When 20 m above the surface, the DropShip would lower the rover on a cable and winch system to touch down gently on the Martian soil. The cables would be cut, with the DropShip then manoeuvring away for a crash landing at a safe distance.

This paper will outline the Mars Precision Lander mission and spacecraft design in detail. Each element of the overall architecture will be presented and the end to end entry descent and landing sequence will be described demonstrating the feasibility of a precise landing on the surface of Mars.

Vision-based navigation solution for soft and precise landing on Mars

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Since 1976 with first US touch down on Mars, landing accuracy has significantly improved from 280x100 km landing ellipse (Viking mission) down to 20x20 km for Mars Science Laboratory (August 2012). Indeed, to maximize the scientific return of planetary exploration missions it is required to land as close as possible to region of scientific interest, calling hence for precision landing.

Based on MSR and Mars Precision Landing scenarios, we propose a light-weight, effective, vision-based navigation solution to perform autonomous, soft and precise landing on Mars. This paper presents state-of-the-art image processing and filter used for vision-based, absolute navigation in approach phase in order to increase navigation precision at Entry point, and during landing phase, necessary conditions to meet precision landing at touch down. Based on studies and demonstrations carried out in the frame of the ESA roadmap for autonomous navigation, the absolute navigation function is also hybridized with terrain-relative navigation inherited from the NPAL solution developed with ESA. In particular, the proposed terrain-relative navigation solution benefits from recent test campaigns with both computer-generated data and real data acquired onboard the ESA PLGTF experiment, demonstrating navigation errors meeting soft and precision landing requirements: during a 160 s long descent, position errors have been kept within 13 m (compared to 1 km if inertial-based navigation only), estimation errors on velocity were less than 0.05 m/s at Touch Down.

Obtaining Atmospheric Profiles during Mars Entry

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In this study we revisit the reconstruction of entry trajectories and atmospheric profiles during Mars Entry Decent and Landing (EDL) with a specific focus on the Phoenix mission. The Phoenix entry probe was well equipped for attitude reconstruction: its IMU's (Inertial Measurement Unit) contain gyroscopes in addition to 3-axis accelerometers. During EDL, Phoenix communicated by radio with various orbiters[1], providing an additional dataset for trajectory reconstruction through analysis of the Doppler shifting. Previous Phoenix studies found discrepancies between angles of attack derived from the accelerometer or gyroscope data. We will revisit the impact of various modeling assumptions including noise reduction methods. The entry trajectories and the atmospheric profiles will be compared with previous Mars entry reconstructions studies as well as with independent orbiter observations such as those by the Mars Climate Sounder (MCS) instrument on the Mars Reconnaissance Orbiter (MRO).

In addition to an IMU system, future Mars entry probes (NASA's Mars Science Laboratory - MSL and ESA's ExoMars EDL Demonstration Module - EDM) are also instrumented with pressure ports on their heat shield. In addition to characterizing the flow in the vehicle's vicinity, those pressures can be used in a FADS (Flush Air Data System) for reconstructing attitude and atmospheric conditions independent of estimated aerodynamic force coefficients. We will discusss the benefits of such as system in addition to IMU's.

M. Sorgenfrei (Student): Revision of a Parametric Entry, Descent, and Landing Design Tool for Mars Exploration

REFINEMENT OF A PARAMETRIC ENTRY, DESCENT, AND LANDING DESIGN TOOL FOR MARS EXPLORATION

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ABSTRACT

Successfully landing robotic systems on the surface of Mars remains a complex engineering challenge for the international space systems community. Despite the successes of the Mars Exploration Rovers and the anticipated arrival of the Mars Science Laboratory this summer, many key parameters of Entry, Descent, and Landing (EDL) at Mars remain either poorly understood or hard to verify. In spite of the complicated environment in which Mars EDL systems must be designed, there is an ever-increasing desire from the planetary science community to land a higher total mass at a higher local elevation within a smaller landing ellipse for the purpose of improved scientific exploration at Mars. For this reason, it is critical to develop EDL-specific design tools that allow the science and engineering communities to better understand design trades early on in the mission development cycle. This is of particular importance for Mars exploration because it is very difficult to replicate for testing the atmospheric and ground terrain conditions with which robotic systems must interact. As such, relatively little experimentation is possible, and the design emphasis must be on simulation-based research.

In this paper, we present refinements to a previously-reported design tool known as Parametric Entry Descent and Landing Synthesis (PEDALS). The objective of PEDALS is to provide a system designer with insight into the EDL trade-space by combining known models such as the MOLA data and Mars-GRAM with a genetic algorithm optimization tool. Genetic algorithms (GAs) make use of concepts from evolutionary biology to search a complex design space, and have been shown to perform well for multi-variable optimization problems such as the design of interplanetary trajectories or launch vehicles. For PEDALS, the genetic algorithm is used to study different solutions to the Mars EDL problem by simulating multiple phases of the EDL process using a range of standard components. For example, an inflatable decelerator paired with a powered landing system may be compared to a lifting body entry vehicle combined with an air-bag type landing mechanism. The GA randomly creates and then tests a population of EDL designs in parallel, and provides the user with an assessment of the performance of each design using standard figures of merit, such as landing ellipse error size. The overall objective of this work is better understand the sensitivity that certain design components have with respect to one another, and to draw conclusions about how well the standard EDL figures of merit reflect the efficacy of certain combinations of standard design elements.

Optimum Sizing for Design of Mars Probes

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The optimum design of a probe for planetary exploration is a complex task involving several disciplines and conflicting objectives (MDO, Multi-disciplinary Optimisation). The solution is typically the result of an equilibrium between all of them in the respect of the constraints. The system engineer is in charge of finding this optimum and his decisions heavily rely on the results of specific analysis tools and simulation results.

This paper presents the methods and tools conceived and consolidated in support to the definition of optimum probes design for Mars exploration with special care to the links between design parameters and performances resulting from Coasting, Entry, Descent and Landing simulations results.

The methods and tools are designed to provide the system engineer with an instrument to perform trade-offs and sensitivity analyses of the end to end system performances from probe separation from the carrier to landing on the Mars surface. The tools, relying on high fidelity simulation results, support decisions on the sizing of the EDL components and the GNC subsystems and also provide inputs to their technology roadmap supporting the definition of requirements for their future development.

In the frame of ESA MREP (Mars Robotic Exploration Programme) studies for Mars exploration, two classes of missions are considered in this paper for which the results of the tools are presented: Mars Network missions where multiple landers separate from the same orbiter and reach the planet surface in different sites, and Mars Single Landers missions where a guided entry phase is required to achieve high landing accuracy levels.

For the Network missions class, the results of the tools for two ESA studies are presented: MarsNEXT (network of landers system study within ESA Aurora programme) and Small Mars Landers (network of landers technology study within MREP programme). For the Single Lander Guided missions, two ESA studies are also presented: MarsPlay (High precision lander system study within MREP programme) and High Precision Landing (High precision and pin-point lander technology study within MREP programme)

The tools presented in this paper are an evolution of the Local and Global Entry Corridor Tools (LEC and GEC) developed and used by the team to perform the entry phase mission analysis of the ESA Exomars probe. Two critical improvements have been introduced: on one side EDL and GNC design parameters are introduced in a multidisciplinary sizing and optimization tool together with mission analysis parameter; on the other side, guided entries on Mars are considered to achieve landing accuracy levels not feasible with simpler ballistic entries.

Several parametric trade-offs and optimization results are presented for the different scenarios considered showing the flexibility of the tools, their adaptability to different objectives and design parameters and their key role in support to European Mars exploration missions and studies.

A. Korzun (Student): Conceptual Modeling of Supersonic Retropropulsion Flow Interactions and the Relationship to System Performance

Conceptual Modeling of Supersonic Retropropulsion Flow Interactions and the Relationship to System Performance

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Supersonic deceleration has been identified as a critical deficiency in extending heritage technologies to the high-mass systems required to achieve long-term exploration goals at Mars. Supersonic retropropulsion (SRP), or the use of retropropulsive thrust while an entry vehicle is traveling at supersonic conditions, is a technology potentially amending this deficiency. SRP aerodynamic-propulsive interactions alter the aerodynamic characteristics of the vehicle, and models must be developed that accurately represent the impact of SRP on system mass and performance. While systems analyses will rely heavily on high-fidelity computational methods to develop these models, existing computational tools and approaches applied to SRP flow interactions are computationally expensive in accurately and consistently simulating the features and behaviors of SRP flowfields. Use of such approaches in support of numerous design trades may be infeasible with current computational capabilities.

In place of high-fidelity aerodynamic analyses, an approximate model for the SRP aerodynamic-propulsive interaction can be used to provide an initial understanding of the significance of SRP configuration on the vehicle's aerodynamic characteristics and the relation of this configuration to other performance metrics traditionally determining vehicle configuration. Establishing high-level relationships between the flow physics governing SRP and design choices related to vehicle configuration and system performance will also assist in determining the fidelity and effort required to evaluate individual SRP concepts.

Experimental efforts have determined that flowfield structure and flowfield stability for SRP are highly dependent on the retropropulsion configuration, the strength of the retropropulsion exhaust flow relative to the strength of the freestream flow, and the expansion condition of the jet flow. Momentum transfer within the flowfield governs the change in the surface pressure distribution of the vehicle, and accordingly, governs the change in the vehicle's integrated static aerodynamic characteristics. Parameters governing SRP aerodynamics have been identified using both experimental trends from the literature and analytical relations of momentum transfer within the SRP flowfield. These analytical relations are specific to highly under-expanded jet flows, contact surfaces, and blunt bodies in supersonic flows.

In this study, a momentum-based, analytical flow model is developed and then used to explore the impact of SRP operating conditions, required propulsion system performance, propulsion system composition, and vehicle configuration on the integrated aerodynamic drag characteristics of full-scale vehicles for Mars entry, descent, and landing. This is completed through assessment of relative changes in surface pressure, integrated aerodynamic drag coefficient, and total axial force coefficient as functions of the maximum vehicle *T/W*, jet flow composition, and the number of nozzles amongst which the thrust is distributed. Relative differences in these quantities and physical changes in flowfield structure are used to identify the fidelity and effort required to support specific design trades for SRP.

Improvement of Experimental and Numerical Tools for Safe and Controlled Martian Entry

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The main objective of the SACOMAR (Key Technologies for Safe and Controlled Martian Entry) project of the European Union FP7 programme is the improvement of experimental and numerical tools for aerothermal design of entry vehicles and study of gas-surface interaction phenomena in the high enthalpy flow field behind the bow shock at Martian entry flow conditions. The improvement of physical modelling using experimental data and its implementation into numerical simulation codes is essential to understand and interpret the physical processes. To achieve this goal the SACOMAR team consisting of scientists and engineers of well established European and Russian research organizations and industries like DLR, ThalesAlenia Italy, Astrium, CIRA, TsNIImash, IPM, TsAGI and ITAM has been formed.

With reference to the EXOMARS trajectory test conditions were identified which enable direct facility-to-facility comparison. Gas phase chemistry in Martian atmosphere and its influence on heat fluxes is a topic that itself is dominated by complex physico-chemical phenomena. Therefore, the geometry of the model that is used for heat flux evaluation should be kept as simple as possible to enable best possible link between heat flux measurements on one side and the measured free stream properties as well as modelling parameters and correlated numerical results on the other side. Vehicles that are supposed to enter Martian atmosphere are designed as blunt bodies which in an hypersonic flow field cause the formation of a strong bow shock on the front side generating substantial heating of the gas and subsequently of the vehicle. Of course, the configuration should reflect this scenario. A well-suited simplification of a capsule-like geometry is a flat-faced cylinder. Compared to other blunt geometries, a flat-faced cylinder provides the largest possible shock stand-off distance for the hypersonic test facilities. By that, it maximizes the experimental possibilities of probing the gas properties in the shock layer. The flat-faced cylinder geometry was used for all experiments. Tests in the short duration facilities allow to simulate thermal and chemical relaxation phenomena comparable with a typical Martian entry flight. In order to have relatively large shock stand-off distance a cylindrical model with a flat front surface is used. A heat flux sensor on the flow axis measures the stagnation point heat flux rate. An identical model philosophy is used in the long duration facilities (Plasmatron and arc heated), which have some limitations in the Reynolds number but are more suitable to measure the gas parameters using spectroscopic measurement techniques. To avoid grid related problems related to sharp edges during numerical simulation the edge of the cylinder was rounded. Finally, a test matrix was defined specifying test conditions in terms of total enthalpy and Pitot pressure for each test facility.

The work related to the physico-chemical modelling aimed modelling improvements in the general areas of high temperature Mars mixture thermodynamic and transport properties, non-equilibrium modelling of dissociation and ionisation and radiation simulation. The focus is on gas transport properties and gas chemistry. Because the heat flux rate in such high enthalpy environment strongly depends on the surface catalysis, surface chemistry modelling is also essential. In addition to experimental activities code-to-code comparison was carried out using the test model geometry of ground testing at real flight conditions. This procedure allows to study the chemical and thermal relaxation phenomena and identify the difference between experiments in ground testing testing facilities and flight. Comparative tests in five different European and Russian high enthalpy facilities showed a clear difference of the Martian atmosphere compared to the air atmosphere with respect to the surface catalytic effects. The dependency of the shock stand off distance on the specific enthalpy, i.e. gas composition has been clearly demonstrated. New recombination coefficients have been determined and are implemented in updated modelling of CFD. This is used for the final CFD simulation of the experiments and extrapolation to flight.

Experimental and Numerical Simulation of Martian Entry Conditions

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Reliable knowledge of probe entry environment is one of key features to achieve success of future Mars missions. This environment strongly depends on Mars entry scenario but also extensively on the thermo-chemical model of Martian atmosphere. Though much work in development of relevant thermochemical model of high-speed/high-enthalpy flows of carbon dioxide (main constituent of the Mars atmosphere) has been done at the moment throughout the world the actual experimental data for hightemperature conditions remain rather scarce and rates of many nonequillibrium processes is known with high degree of uncertainty (of order of magnitude and even greater). Thus any new experimental data obtained in high-enthalpy conditions will contribute to the improvement of existing chemical and physical models for such kind of flows.

A number of new experimental data were obtained during test campaign in high-enthalpy inductively coupled plasmatron facility U-13 of TsNIImash (Russia) within the frameworks of EU FP7 SACOMAR project (Key Technologies for Safe and Controlled Martian Entry). This work includes studies of surface heterogeneous catalysis in CO_2(97%)+N_2(3%) flow by specification of heat fluxes to three different surface materials – silver, copper and quartz at two flow enthalpies – 9 and 13.8 MJ/kg and several reference values of Pitot pressure from 10 to 80 hPa. These enthalpies used in tests refer to two trajectory points of future EXOMARS probe.

Presented report addresses the results of flow diagnostics in U13 ICP facility as well as test results obtained in the course of experimental campaign, primarily on the catalytic properties of studied surface materials in high-enthalpy carbon dioxide flow. Also, these experiments were rebuilt by means of CFD code that includes solution of combined Maxwell – Navier-Stokes equations for nonequillibrium gas mixture in the facility inductor and Navier-Stokes equations for work section/test model flow. Similar CFD modelling were made for the referenced trajectory points of EXOMARS probe using nonequillibrium compressible Navier-Stokes solution code.

Acknowledgments: The work presented in this paper was made within the project SACOMAR (Technologies for Safe and Controlled Martian Entry) funded by European Commission under Grant agreement no. 263210.

SIMULATION OF HEAT TRANSFER AND SURFACE CATALYSIS FOR EXOMARS ENTRY CONDITIONS

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At EXOMARS probe entry velocity below 6000 m/s a large portion of the heat load on TPS appears due to convective heating. At moderate surface catalycity heterogeneous recombination of O atoms and CO molecules introduces a main part of uncertainty in laminar heat flux rates. So surface catalysis in terms of $O + O \rightarrow O_2$ and $CO + O \rightarrow CO_2$ reactions is one of the key problems of thermal protection materials development, testing and selection. In Refs. 1 and 2 an indirect methodology of rebuilding efficient catalytic recombination coefficients γ_O and γ_{CO} was developed and applied to predict these coefficients for quartz and Silica-based material, though it was assumed that $\gamma_O = \gamma_{CO}$.

In the present paper a new self consistent 2-parameter model of surface recombination of O atoms and CO molecules is proposed and novel methodology for numerical rebuilding γ_O and γ_{CO} is developed. The following essential parts of the methodology are presented: 1) production of the dissociated subsonic stable CO_2 flows according test matrix; 2) experimental study of the steady-state heat transfer in stagnation point configuration; 3) demonstration of comparative catalycity heating effect and establishing catalycity scale for different cold wall materials; 4) search and application of the high catalytic material, which surface can be considered as reference fully catalytic one; 5) CFD modeling reacting plasma and high enthalpy CO_2 flows within plasma torch and around a test model; 6) rebuilding free stream conditions (enthalpy, velocity); 7) model of surface catalysis; 8) numerical computations of nonequilibrium multicomponent boundary layer flows modified for low Re test conditions taking into account the finite thickness of the boundary layer; 9) design of the heat flux envelopes for the subsonic test conditions; 10) uncertainties analysis; 11) extrapolation from ground test to atmospheric entry conditions.

Heat transfer tests have been performed by 100-kW RF-plasmatron in subsonic high-enthalpy CO_2 flows at the enthalpies (9 and 13.8 MJ/kg) and stagnation pressures (40 and 80 hPa) relevant to EXOMARS entry trajectory. Heat flux rates to cooled silver, copper, stainless steel and quartz surfaces have been measured in four test regimes in stagnation point configuration using 50-mm diameter model. Significant catalytic heating effect was observed and qualitative catalytic scale was established as follows: Ag > Cu > steel > SiO_2. Strong oxidation of the silver surface during long exposure was registered. Heat flux to silver surface reached maximum value in about 15 min. Dynamic pressure was measured and enthalpy numerically rebuilt assuming that maximum heat flux to silver corresponds to fully catalytic wall. Effective recombination coefficients of O-atoms and CO-molecules (γ_w) on water-cooled copper, stainless steel and quartz probe in the four selected subsonic high-enthalpy carbon dioxide flow regimes are determined and compared using IPM standard [1, 2] and new methodologies.

This work has been performed in the framework of SACOMAR (REA EC) project and RFBR project 11-01-00111-a.

1. Kolesnikov, A., Pershin, I., Vasil'evskii, S., Yakushin, M.: Study of Quartz Surface Catalycity in Dissociated Carbon Dioxide Subsonic Flows. AIAA Paper 98-2847, June 1998 (J. Spacecraft and Rockets, Vol. 37, No. 5, 2000, pp. 573-579).

2. Kolesnikov, A.F., Pershin, I.S., Vasil'evskii, S.A. Predicting Catalycity of Si-Based Coating and Stagnation Point Heat Transfer in High-Enthalpy CO_2 Subsonic Flows for the Mars Entry Conditions. Proc. Int. Workshop "Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science", Lisbon, Portugal, 6-9 October 2003 (ESA SP-544, February 2004), pp. 77-83.

Technology Development toward Mars Aeroflyby Sample Collection

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In Japan Aerospace Exploration Agency, Mars Aeroflyby Sample Collection (MASC) mission is currently entertained as a part of Japan's new and ambitious plan for a series of Mars exploration missions, MELOS (an acronym of Mars Exploration with Lander-Orbiter Synergy). In a mission scenario, an atmospheric entry vehicle of aero-maneuver capability is flown into the Martian atmosphere, collects the Martian dust particles as well as atmospheric gases during the guided hypersonic flight, exits the Martian atmosphere, and is inserted into a parking orbit from which a return system departs for the earth to deliver dust samples. The conceptual design of the MASC system is shown in Fig. 1. In order to accomplish controlled flight and successful orbit insertion, aeroassist orbit transfer technologies are introduced into the vehicle's guidance and control system. The system analysis is performed to assess feasibility of the MASC system and to make a conceptual design, finding that the MASC system is feasible at the minimum system mass of 600 kg approximately.

Research and development of key technologies are currently going on. An aerodynamic design of the vehicle is determined with optimization for aeroflyby sample collection, and tested in hypersonic wind tunnels. A laboratory model of the aeroshell equipped with a non-ablative light-weight thermal protection system (NALT), which is designed to eliminate contaminants originating from the thermal protection materials, has been developed and has undergone comprehensive tests. The carbon aerogel and the silica aerogel, which are the promising candidates for Martian dust capture, are tested by arcjet heating to examine their behavior when exposed to high-temperature gases, as well as by particle shooting to examine their dust capturing capability.

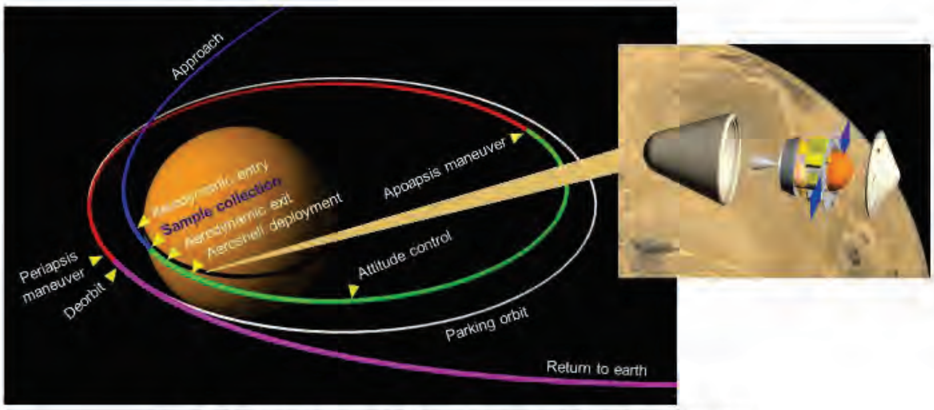

Fig. 1 Schematic view of Mars Aeroflyby Sample Collection

Robust Autonomous Aerobraking Strategies

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Aerobraking is an aero-assist technique that allows significant reduction of propellant mass on missions to planets with atmospheres, typically Mars and Venus. It consists in using the braking effect of atmospheric drag over a series of periapsis passes in order to reduce the spacecraft orbit energy and therefore its orbital period and apoapsis altitude until the operational orbit is reached. The total propellant mass gain with respect to a fully propulsive planetary orbit insertion manoeuvre can be huge, typically around 300kg for Mars missions. Aerobraking has been successfully performed by Mars Global Surveyor, Mars Odyssey and Mars Reconnaissance Orbiter US missions. An aerobraking experiment is planned in 2014 for the Venus Express mission developed by Astrium, which will allow improving the operational experience in Europe, enabling the use of aerobraking on future missions to Mars.

Although very beneficial in terms of propellant mass, aerobraking is inherently a hazardous phase since it repeatedly exposes the spacecraft to atmospheric heat flux, risking over-heating of a spacecraft component (typically solar arrays which are the main drag area), or even mission loss. Aerobraking is also a long mission phase, of typically a few months, during which ground involvement is very high including activities such as orbit restitution and prediction, atmospheric conditions monitoring and prediction, manoeuvre decision-making, etc. under tightening time constraints. This heavy workload not only has a high cost that offsets the launch cost savings of aerobraking, but also increases the risk of human error. Furthermore, US experience has shown that atmospheric variability quickly turns ground-based operational sequences obsolete, imposing frequent ground updates in order to keep a correct matching between sequences and actual orbit events. Autonomy is a way to mitigate those issues and increase overall aerobraking robustness, in particular after the orbital period has decreased under a critical duration under which ground teams cannot react from one orbit to the next. This paper presents algorithms and methods that have been designed in order to increase the autonomy level of the aerobraking phase.

In a first autonomy level, the operational sequences that are generated by the ground and uplinked to the spacecraft are autonomously corrected thanks to on-board measurement of key aerobraking events and parameters: estimation of periapsis pass date, heat flux, atmospheric drag ΔV. In this way the required frequency of ground updates is decreased, relaxing the pressure on ground teams. In addition to this, on-board monitoring of critical parameters (such as solar array temperatures and convective heat flux) gives the capability to autonomously command a safeguard action in case of exceeded threshold on such parameters. This is extremely valuable when the ground has not enough time to react before the next periapsis pass (end of aerobraking). In a second step towards increased autonomy, onboard algorithms are proposed in order to perform autonomous corridor control, i.e. manoeuvre decision-making and computation, so that ground teams may focus on higher-level activities such as atmosphere monitoring and aerobraking corridor tuning. Eventually, a new safe mode is proposed that copes with the specificities of the aerobraking phase, removing the need for costly pop-out maneuvers while guaranteeing spacecraft safety. This work was performed in the frame of ESA study "Robust Autonomous Aerobraking Strategies" (contract No. 4000102049).

IPPW-9 Dynamical study of the aerobraking technique in the atmosphere of Mars

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Aerobraking is an aero-assisted orbital maneuver around a planetary body consisting in changing from an initial elliptical orbit with pericenter inside the planet's atmosphere, to smaller and smaller orbits until complete circularization is reached. The maneuver is based on the effect of atmospheric resistance on the orbit at every passage of the spacecraft through the atmosphere. This technique enables considerable fuel savings, which in turn may mean higher payload masses.

Aerobraking maneuvers have been carried out by Hiten (1991) in a swingby with the Earth, Magellan (1993) at Venus and Mars Global Surveyor (1997), Mars Odyssey (2001) and Mars Reconnaissance Orbiter (2006) at Mars. As an example, the Magellan spacecraft was able to improve the resolution of the gravity field measurements at high latitudes at Venus by reducing the apocenter altitude. Thanks to an aerobraking maneuver, it did so with less than the available 94 kg of propellant, thus saving more than 800 kg with respect to the propulsion-only solution.

In this study, we set up a dynamical model consisting in a full spherical harmonics representation of the gravitational acceleration induced by the central planet, atmospheric drag and any other significant perturbations (Sun and/or Jupiter third body effects, radiation pressure accelerations). Then, by numerical integration, we simulate the aerobraking trajectories that result from adopting a range of spacecraft parameters (e.g., the ballistic coefficient) in a model atmosphere and gravity field with a set of atmospheric entry conditions (position and velocity vector of the spacecraft). The output is a comparison of aerobraking scenarios in terms of circularization time and associated number of orbits, final conditions (position and velocity of the spacecraft) and fuel savings relative to a propelled circularization strategy. The planet chosen for the study is Mars, for which accurate gravity and atmospheric models are available. The way in which these models are linked to the aerobraking simulation code is also described in the work.

Session 6A: Cross-Cutting Technologies I

N. Cheatwood: NASA Game Changing Development Program - Entry, Descent, and Landing Overview (Invited)

K. Edquist:

NASA Game Changing Development Program – Entry, Descent, and Landing Overview

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NASA has created a new program office that is responsible for fostering the development of innovative, disruptive technologies designed to revolutionize the current paradigms for spacecraft. One popular theme within the program office is that of Entry, Descent, and Landing (EDL). This paper will provide an overview of the philosophy for EDL technology growth, and will give specific examples of current projects engaged in EDL technology development within the Office of the Chief Technologist.

At the time of this submittal the NASA Game Changing Program Office is currently supporting three technology investments 1) Hypersonic Inflatable Aerodynamic Decelerators (HIAD), 2) Deployable Aeroshell Concepts, and 3) an innovative Woven Thermal Protection System. This paper will highlight the goals of each of these projects and explain the game changing benefits of each.

In addition to the currently funded projects, the authors will expand on goals for EDL innovation and supply some current thoughts related to 1) Trim tabs, 2) Supersonic Retro-propulsion, 3) Landing System Technology and 3) Next Generation Parachute Technology.

Ultimately, the goal of this paper is to inform the community of the interest that NASA has in spurring EDL technology development, as well as provide a call to the technical community to engage with NASA and develop ideas that will ultimately mature technologies requisite for next generation EDL systems.

Supersonic Retropropulsion Technology Development in NASA's Entry, Descent, and Landing Project

Supersonic Retropropulsion Technology Development in NASA's Entry, Descent, and Landing Project

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NASA's space technology roadmap calls for human exploration of Mars in the coming decades. To achieve that goal, the Entry, Descent, and Landing (EDL) roadmap (TA09) recommends new supersonic deceleration technologies to succeed traditional parachutes, the latter of which do not scale well for human payloads (10s of metric tons). One of those technologies, termed Supersonic Retropropulsion (SRP), involves using propulsive deceleration at supersonic Mach numbers, rather than just during the terminal descent phase. NASA's EDL project spent two years advancing the technology readiness level of SRP for Mars exploration. The current paper summarizes the technical accomplishments from the project and highlights the challenges envisioned for future SRP technology development programs. The major accomplishments include: completion of a draft roadmap outlining key milestones for advancing SRP; completion of two wind tunnel tests designed specifically to provide data for validation of computational fluid dynamics (CFD) models; an initial assessment of a suite of CFD codes against wind tunnel data, augmented with experimental uncertainties; and completion of a conceptual level study for an initial Earth-based flight demonstration.

The major challenges and roadblocks for these accomplishments, as well as those envisioned as the technology advances in the future, will be covered in the paper. These challenges include: testing and computationally modeling complex and unsteady SRP fluid dynamics, and scaling those effects to flight conditions; predicting the potential effects of unsteady SRP fluid dynamics on the stability and controllability of proposed entry systems; developing sufficiently large SRP engines for use on human-scale entry systems; and demonstrating sub-scale SRP entry systems in Earth's atmosphere to validate analytical models and reduce risk for future missions.

Adler, M., Wright, M., Campbell, C., Clark, I., Engelund, W., and Manning, R. M.,\DRAFT Entry, Descent, and Landing Roadmap, Technology Area 09," National Aeronautics and Space Administration, http://www.nasa.gov/oces/oct/home/roadmaps/index.html, November 2010.

Edquist, K. T., Dyakonov, A. M., Korzun, A. M., Shidner, J. D., Studak, J. W., Tigges, M. A., Trumble, K. A., and Dupzyk, I. C., "Development of Supersonic Retro-Propulsion for Future Mars Entry, Descent, and Landing Systems," AIAA Paper 2010-5046, 10th AIAA/ASME Joint Thermophysics and Heat Transfer Conference, Chicago, IL, 30 June-1 July, 2010.

Berry, S. A., Rhode, M. N., Edquist, K. T., and Player, C. J., "Supersonic Retropropulsion Experimental Results," AIAA Paper 2011-XXXX, 42nd AIAA Thermophysics Conference, Honolulu, HI, 27-30 June, 2011.

Kleb, W., Carlson, J., Buning, P., Berry, S., Rhode, M., Edquist, K., Schauerhamer, D., and Trumble, K., "Toward Supersonic Retropropulsion CFD Validation," AIAA Paper 2011-XXXX, 42nd AIAA Thermophysics Conference, Honolulu, HI, 27-30 June, 2011.

Trumble, K. A., Kleb, W., Carlson, J.-R., Buning, P., Edquist, K. T., Schauerhamer, D. G., and Barnhardt, M. D., "An Initial Assessment of Navier-Stokes Codes Applied to Supersonic Retro-Propulsion," AIAA Paper 2010-5047, 10th AIAA/ASME Joint Thermophysics and Heat Transfer Conference, Chicago, IL, 30 June-1 July, 2010.

Aerothermal Ground Testing of Flexible Thermal Protection Systems for Hypersonic Inflatable Aerodynamic Decelerators

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The Hypersonic Inflatable Aerodynamic Decelerators (HIAD) project has invested in ground tests to evaluate the aerothermal performance of various thermal protection system (TPS) candidates for use in inflatable high-drag, down-mass technology. A flexible TPS enables large deployable aeroshells which significantly reduce the ballistic coefficient of an entry vehicle allowing a greater mass to be delivered to the ground with higher accuracy than traditional rigid ablator heat shields. A HIAD requires a TPS capable of surviving the aerothermal loads of heat flux, pressure, shear force, and total energy load.

Flexible TPS research involves ground testing and analysis necessary to characterize performance of the flexible TPS candidates prior to flight testing. This paper provides an overview of the analysis and ground testing efforts performed over the last year at the NASA Langley Research Center and in the Boeing Large-Core Arc Tunnel (LCAT). In the LCAT test series, material layups were subjected to aerothermal loads commensurate with peak re-entry conditions enveloping a range of HIAD mission trajectories. The TPS layups were tested over a heat flux range from 20 to 50 W/cm² with associated surface pressures of 3 to 8 kPa.

To support the testing effort a significant redesign of the existing model holder from previous testing efforts was undertaken to develop a new test technique for supporting and evaluating the TPS in the high-temperature, arc jet flow. Since the flexible TPS test samples typically experience a geometry change during testing, computational fluid dynamics (CFD) models of the arc jet flow field and test model were developed to support the testing effort. The CFD was used to help determine the test conditions experienced by the test samples as the surface geometry changes. This paper includes an overview of the Boeing LCAT facility, the general approach for testing flexible TPS, development and results of the CFD analysis, the in-depth TPS thermal analysis methodology and thermal results comparing the various TPS layups.

Optimized StarBody Waverider Shapes for Lifting Aerocapture

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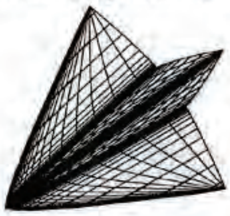
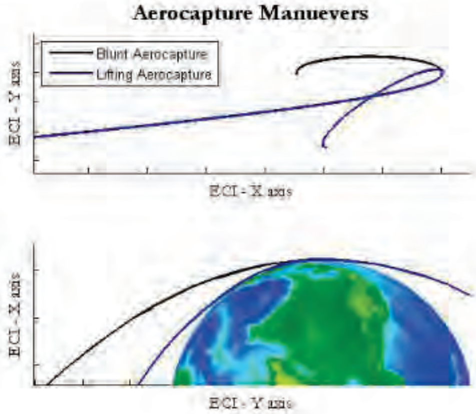
Traditional aerocapture maneuvers are extremely high risk, involving extremely precise control of ehicles operating at the very limit of their design margins. The heavy constraints have led mission esigners to other, more traditional and more propulsively expensive options. Performing an aerocapture ıaneuver with a lower drag, lift generating body is an alternate option which increases the margin for rror during execution. Whereas the traditional aerocapture sheds excess hyperbolic velocity in a quick eriapsis fly-by, the proposed vehicle would use lift to augment gravitational force, allowing the vehicle) remain exposed to atmospheric drag for a longer period of time, thereby gradually decelerating to rbital velocities. This allows lower heating rates, broadening the potential thermal management trategies. Furthermore, if a lifting body is used, greater propulsive savings can be found by imparting lane change simultaneously. While the vehicle is in atmosphere, a portion of the lift vector could be used) turn away from the initial inclination and towards the desired final orbit at the target planet.



StarBody vehicles (see. Fig. 1) are an ideal choice for such missions as they demonstrate the low drag behavior of other waveriders with the added benefit of inherent stability. They are statically stable in roll, and depending on the design, typically show benefits over other waveriders in yaw and pitch stability as well. In this study, the number, layout and size of so-called "tines" was optimized to determine the optimum design for a lifting aerocapture maneuver. Varying these three parameters changes the ratio of pressure to viscous drag, enabling a design ideal for decelerating from hyperbolic velocity in a stable and controlled manner.

The optimization was run with two main metrics for comparison: altitude of apoapsis and a uantification of turning. All designs were given the same initial velocity at entry to the target planet's phere of influence on a trajectory with an atmospheric periapsis. The trajectory was then propagated by ıtegrating aerodynamic and gravitational forces. Once the vehicle entered the atmosphere, it was ssumed to be flown upside down at an angle of attack slightly above maximum lift-to-drag ratio but a ıctor of safety within the stability margin. Once the vehicle reached the subsequent orbital apogee, the imulation was stopped. The lower the altitude, the more ffective the aerocapture maneuver. However, a second ıetric was necessary to promote higher lift-lower drag esigns. This was the maximization of turning (see Fig. 2), /hich represented the amount of time the vehicle spent in the tmosphere. For further comparison with other aerocapture esigns, profiles of the following were also generated: elocity, dynamic pressure, and post-shock temperature..

Aerocapture Manuevers



Through this analysis, it was shown that aerocapture perations are possible with non-blunt body vehicles. A range f locally optimized designs were created which would allow ıermal loads to be much lesser than similar high drag forms. tarBodies demonstrate great benefits over even other lifting /averiders, including extremely important stability behavior.

Sub-scale, high-altitude testing of parachutes; a low-cost methodology for the characterisation of parachutes for planetary entry

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This paper will discuss a low-cost method for characterising parachutes designed for low-density, high-speed deployment, such as those required for planetary entry or sample return.

NASA conducted a range of high altitude tests in the context of the Viking mission during the 1960's. The NASA tests cover Mach numbers of 1.16 to 3.31 and were used to initially compare several parachute configurations (disk gap-band, cruciform and ring sail) and finally to qualify the selected disk-gap-band design[1]. The Huygens programme also included a single balloon launched high altitude drop test which allowed end to end testing of the three parachute sequence[2]. Four balloon launched parachute tests were carried out during precursor testing for the Mars Science Laboratory programme[3]. The ExoMars programme also will use two high altitude drop tests to qualify the parachute system.

Testing at high altitude is required to obtain the combination of transonic / supersonic Mach numbers and low dynamic pressure. Moreover, parachute flight dynamics are quite different in low density atmospheres so this also can be investigated. All the tests discussed are at full scale and expensive to conduct. To properly characterise and develop parachutes many tests need to be conducted and so lower cost testing is essential. One approach used in the ExoMars programme was to test at high altitude but at subscale. Vorticity and Cambridge University Space Flight developed a low cost subscale 11 kg test vehicle capable of deploying a 2.55 m diameter parachute at Mach 0.8 at over 24 km altitude. The test vehicle was fully instrumented with a pitot-static probe, accelerometers, rate gyros, GPS and a camera. Sensors and cameras mass-produced for consumer market are utilised in a small, light instrumentation package. Commercial weather balloons are used to carry the vehicle to altitudes in excess of 24km (79,000ft) where ambient air density is < 5% of sea level.

Subscale high altitude testing will continue in a European Space Agency funded study to characterise subsonic parachutes for extra-terrestrial missions. This will include clusters and gliding parachutes in addition to heritage designs.

This technique allows repeated experimental data to be collected at a cost that is 1-2 orders of magnitude lower than those previously used, and paves the way for improvements such as rocket-accelerated balloon launched test vehicles, which can provide significantly higher Mach numbers than free-fall.

References

1 Aerodynamic Decelerators for Planetary Exploration: Past, Present and Future. Cruz, Juan R and Lingard, J Stephen. Keystone, CO : AIAA Guidance Navigation and Control Conference and Exhibit, 2006. AIAA 2006-6792.
2 A system drop test of the Huygens Probe. Underwood, J.C. AIAA Aerodynamic Decelerator Systems Technology Conference, 14th, San Francisco, CA, June 3-5, 1997. AIAA-1997-1429.
3 High Altitude Test Program for a Mars Subsonic Parachute. Mitcheltree, Robert, et al., et al. Munich: 18th AIAA Aerodynamic Decelerator Systems Technology Conference, 2005. AIAA 2005-1659.

Modeling the Structural Performance of Hypersonic Inflatable Aerodynamic Decelerators

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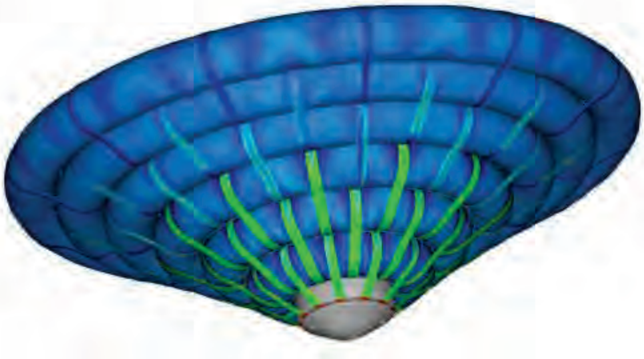
Hypersonic inflatable aerodynamic decelerators (HIADs) offer considerable advantages over rigid aeroshell technology for human and robotic missions requiring atmospheric entry. Most noteworthy are the considerable system mass and volume fraction savings over conventional rigid aeroshells. Furthermore, deployable systems promise a much broader range of landing altitudes and entry masses that support comprehensive exploration.

Currently, HIADs are being considered for returning payloads from low earth orbit and landing heavy payloads on the surface of Mars. The ongoing Inflatable Re-entry Vehicle Experiment (IRVE) program has successfully demonstrated various aspects of HIAD technologies including exo-atmospheric inflation, inflatable structure performance, thermal protection system performance, and aerodynamic stability.

This paper documents the finite element structural analysis of the 3 meter diameter IRVE-3 inflatable decelerator. The HIAD project selected a stacked torus configuration for the IRVE-3 inflatable aeroshell for improved stiffness and rigidity. A stacked torus consists of increasing diameter, pressurized tori joined together to form a conical structure. Each torus consists of a fiber reinforced braided tube with a gas barrier liner. The stacked torus is joined to a center-body using load straps and covered with a flexible Thermal Protection System (TPS) to reduce the thermal loading on the inflatable structure. This paper discusses the development of an LS-DYNA transient explicit FEA model of the complex stacked torus configuration. Model predictions and structural ground test results are compared, and the results of flight performance loading simulations are discussed. In addition, the model has been used to demonstrate scalability of the configuration and guide the design of a 6 meter diameter stacked torus HIAD. Subsequently, model predictions of the 6 meter design have been compared with structural ground tests.



HEART Flight Test Overview

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High Energy Atmospheric Reentry Test (HEART) demonstrates the utility of the Hypersonic Inflatable Aerodynamic Decelerator (HIAD) technology via an inflatable, low ballistic coefficient entry system entering the atmosphere from Low Earth Orbit (LEO). HEART is an entry vehicle with an 8.3 m maximum diameter and an entry mass capability of 4000 to 5000 kg. HEART will demonstrate an entry capability commensurate with planetary entries, including Earth up to GEO, such that all relevant environmental parameters needed for maturation are met with the HEART flight test.

Current planetary entry systems typically use rigid aeroshells to develop aerodynamic drag and lift to decelerate the vehicle and control its flight path through the atmosphere and to host the thermal protection system (TPS) which protects the vehicle from the entry aerothermal environment. Launch vehicle fairing size limits the maximum diameter of a rigid aeroshell leading to constraints on the entry vehicle's ballistic coefficient. With a vehicle's atmospheric deceleration profile governed by its ballistic coefficient, reducing a vehicle's ballistic coefficient, leads to deceleration higher in the atmosphere, providing more time between atmospheric interface and landing to deploy parachutes, sense ground hazards, and fire thrusters for safer, more precise landings at higher elevations. This key benefit of the HIAD technology is demonstrated via HEART, that of a deployable entry aeroshell not constrained principally by the launch vehicle fairing. HIAD technology fulfills this need with the capability to dramatically increase the entry vehicle drag area and lower the vehicle ballistic coefficient. The HIAD flexible structure stows in a small volume for launch (2.5 m diameter), and then deploys to a much larger diameter (8.3 m) prior to atmospheric entry, providing over three times the drag area of the largest rigid aeroshell to date.

The HEART mission uses a stacked torus configuration to achieve the axisymmetric 55 to 60 degree sphere cone shape. A central rigid aluminum structure provides the base for the nose to meet the desired nose curvature, to provide the load path for launch and entry loads. Protection of the vehicle from the 40 W/cm^2 peak heat rate aerothermal environment is achieved through a multi-layer flexible, insulating TPS. HIAD inflation is performed by a compressed nitrogen, blowdown system. Since HEART is envisioned to be an uncontrolled, ballistic entry from LEO flight demonstration mission with a limited operational lifetime, on-board systems are simplified to the essential few, such as a sequencing controller, battery power, telecommunications, thermal control, and sensors and data signal processing. The HEART flight test phase concludes when the vehicle has been decelerated to a Mach number of 0.7. Disposal into the Pacific Ocean without recovery, is the baseline conclusion of the HEART mission.

HEART is currently in the concept development phase including mission requirements, operational strategies, and configuration definition. Technology needs for the HEART flight test are met through the HIAD project (part of the Game Changing Division within NASA's OCT), such that no additional technology developments are needed after the project receives the formal go-ahead. HEART is also partnering with NASA's Human Exploration and Operations Mission Directorate to use the existing ISS Cargo Resupply Contract spacecraft as the provider of the host spacecraft, launch services, and operations services. The HEART entry is planned for late 2016.

Design and Verification of Full-Scale Inflatable Aeroshell Structures for Hypersonic Applications

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Abstract

Studies have shown that, due to atmospheric constraints at high altitudes and excessive deceleration loads with high-mass payloads, 50% of the surface of Mars is currently inaccessible to landing with existing Entry, Descent, Landing (EDL) technologies[i]. Lowering the ballistic coefficient of a probe by increasing the size of the probe's decelerator allows the system to land in a reduced-density atmosphere or at higher mass. Launch vehicles limit the size of rigid aeroshells since they must fit within the launch fairing, and future planetary probes will require the use of deployed structures to increase drag area. Future missions may require decelerators of 6 to 25 meters in diameter in order to land payloads of up to 50 mT. Hypersonic Inflatable Aerodynamic Decelerators (HIADs) provide a potential solution. The stacked torus configuration is the current top contender for HIADs due to its shape accuracy and scalability. Development of the stacked torus configuration is currently being conducted on the Inflatable Reentry Vehicle Experiments – 3 (IRVE-3) and HIAD Large Article Ground Test Campaign. This paper will discuss the development process, including analytical modeling, finite element analysis, coupon/component testing, and full system verification testing. The results have shown stacked torus HIAD designs to be feasible over a range of sizes and loading conditions.

[i] Zang, T. A. (Editor), "Entry, Descent and Landing Systems Analysis Study: Phase 1 Report," EDL Systems Analysis Team, NASA TM-2010-0000002009, May 2010.

Flexible Thermal Protection System Design and Margin Policy

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Hypersonic Inflatable Atmospheric Decelerator (HIAD) technology represents an entry system that offers the potential to achieve several future planetary exploration missions that cannot be accomplished today. The NASA HIAD project is currently focused on advancing the maturity of key technology requirements of this promising capability for flight demonstration and eventual mission infusion. Critical to the success of the inflatable decelerator capability is the flexible thermal protection system which must be a weight optimized design that assures with sufficient reliability that the inflatable structure will be protected from the extreme conditions imposed by the entry environment. Flexible thermal protection systems are a nascent technology enabled by current advancements in high temperature materials. The HIAD project is pursuing a heat shield technology that is a modular, multilayered insulation system consisting of a refractory textile outer layer designed to accommodate peak heating that is layered over insulators designed to manage integrated heat loads such that the temperature on the gas barrier back-face remains below its performance limits. In order to take full advantage of new materials within a flexible heat shield design, a safe design approach must be implemented which avoids using traditional heat shield sizing methods of stacked offset margins which are thought to be overly conservative and are likely to impose undesirable limits on a mission. The HIAD project is establishing a reliability-based design margins approach that will be used to obtain a weight-optimized heat shield that incorporates uncertainty analysis entry loads and material response. The principal feature of the design approach will be to link the design of the thermal protection system with a dispersed trajectory analysis for a proposed mission as an un-margined performance requirement using a Monte Carlo simulation technique. Predictions for the dispersed trajectories of a mission are used as a random variable inputs to an uncertainty analysis of the heat shield system together characterized uncertainties for the key properties of the heat shield and its constituent materials. The Monte Carlo approach results in a predicted distribution for heat shield mass which forms a rational basis for assessing reliability metrics for a final heat shield design. A thorough understanding of the underlying thermal management physics, inherent uncertainties in material response, and deficiencies in the physical model are required to rigorously evaluate design margins. This design margin methodology is currently being linked with high fidelity thermal model formulated using the COMSOL analysis software package. This paper describes recent progress in establishing this paradigm change to sizing an entry thermal protection system and provides a first order estimate of the potential effect on weight and performance.

Flexible Thermal Protection System Development for Hypersonic Inflatable Aerodynamic Decelerators

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Hypersonic Inflatable Aerodynamic Decelerators (HIAD) project has invested in development of multiple thermal protection system (TPS) candidates to be used in inflatable, high down-mass, technology flight projects. Flexible TPS is the element of the HIAD project tasked with the research and development of all aspects of the technology ranging from direct ground tests, modelling and simulation, characterization of TPS systems, manufacturing and handling, and standards and policy definition. The intent of flexible TPS is to enable large deployable aeroshell technologies, which increase the drag performance while significantly reducing the ballistic coefficient of high-mass entry vehicles. A HIAD requires a flexible TPS capable of surviving the aerothermal loads, and durable enough to survive the rigors of construction handling, high density packing, long duration exposure to extrinsic in-situ environments, deployment, and aerodynamic loading.

This paper provides a comprehensive overview of all work being performed within the Flexible TPS element of the HIAD project. Included in this paper is an overview of, and results from, each Flexible TPS research and development activity, which includes ground testing, physics based thermal modelling, age testing, margins policy, catalysis and materials characterization, and recent developments with new TPS materials.

Deployable Aeroshell Technology Maturation Plan and Progress: Enabling Planetary In-Situ Science Missions

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We propose to present the GCD funded project plans and progress made to-date to mature the Deployable Aeroshell Concept (DAC) from a technology maturation level from 3 to 5 in two years time frame. The DAC concept, also known as Adaptive, Deployable Entry and Placement Technology (ADEPT), is a mechanically deployable semi-rigid aeroshell entry system to achieve low ballistic coefficient during entry. The concept is akin to an umbrella with a flexible and deployable carbon fabric integrated to the underlying deployable mechanical system. The woven carbon fabric, which covers large portion of the frontal surface and supported by rigid ribs, is the primary drag-producing surface. Its flexibility allows it to be stowable and deployable. The carbon fabric also provides significant thermal protection capability. The carbon fabric will encounter high heating during entry and with its high thermal conductivity, allows re-radiation from both the windward and leeward side of the fabric. As a result, this concept is a mass efficient drag device.

The mechanically deployable concept was originally developed for Mars missions with very heavy payloads, much greater than the MSL class, to be delivered to the surface and is described, in detail in Reference 1. The Mars concept requires guided entry and hence in the original concept, the deployment systems associated with the aero-surface was designed so that it allows the vehicle to be guided via changing the lift vector orientation during entry. In addition, the deployed aeroshell is reconfigured so that just prior to entry, it becomes the landing attenuation system with the carbon fabric skin providing limited protection from debris field generated by the retro-rockets. The concept for Mars is shown in Figure 1.

At the IPPW8 in Norfolk, Virgina, we presented the benefit of Low Ballistic Coefficient Aeroshell Technology (LBCAT) for robotic in-situ science missions (Ref. 2) such as Venus, Saturn and Uranus. One major benefit of low ballistic coefficient is that deceleration is achieved at much higher altitudes during entry, thus resulting in peak conditions such as heat-flux, pressure and integrated heat-load much lower (one to two orders of magnitude lower) compared to rigid aeroshell. In the case of planetary in-situ science missions to Venus, Saturn, Uranus and Neptune, simpler ballistic entry will be sufficient to meet the science requirements. The deployable aeroshell concept, as a result of ballistic entry, will not require lift vectoring and the associated guidance, navigation and control, and thus will result in much lower life cycle cost, both technology development as well as mission execution costs. The design is also simpler for ballistic entry (Figure 2).

We presented parametric studies performed to characterize the entry environment as a function of ballistic coefficient and entry flight path angle for Venus, Saturn and Uranus.

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Session 6B Earth Entry & Sample Return

J. Bouilly: RASTAS SPEAR : Radiation Shape Thermal Protection Investigation for High Speed Re-Entry (Invited)

RASTAS SPEAR : Radiation-Shapes-Thermal Protection Investigations for High Speed Earth Re-entry

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ABSTRACT:

An important step for Space Exploration activities and for a more accurate knowledge of the Earth, universe and environment is to develop the capability to send vehicles into space, which collect and return to Earth samples from solar system bodies. To return these samples, any mission will end by high-speed re-entry in Earth's atmosphere. This requires strong technological bases and a good understanding of the environment encountered during the Earth re-entry.
Investment in high speed re-entry technology development is thus appropriate today to enable future Exploration missions such as Mars Sample Return. Rastas Spear project started in September 2010, with the main objective to increase Europe's knowledge in high speed re-entry vehicle technology to allow for planetary exploration missions in the coming decades.
The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 241992.

The project's main objective can be derived in sub-objectives as follows:

- **OBJ1**: To better understand phenomena during high speed re-entry enabling more precise Capsule sizing and reduced margins.
- **OBJ2**: To identify the ground facility needs for simulation
- **OBJ3**: To master heat shield manufacturing techniques and demonstrate heat shield capabilities.
- **OBJ4**: To master damping at ground impact and flight mechanics and thus ensure a safe return of the samples.

This study is carried out by a consortium of European companies and institutes : VKI (B), Kybertec (Cz), Demokritos (Gr), IoA (Pl), CIRA (I), CFS (CH), MSU (Ru), CNRS and ONERA (F), and coordinated by Astrium (F).
After shortly reminding the organisation and objectives of the project, the scope of this paper is to present the main results obtained until now within the RASTAS SPEAR project, aiming at enhancing the basic capabilities on some specific topics such as:

- Aeroshape stability
- High speed aerothermal environment
- Sub-system / equipment : Thermal protection, Crushable material

Post-Flight Analysis of the Hayabusa Sample Return Capsule

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Hayabusa sample return capsule (SRC), separated from the mother spacecraft, entered the earth atmosphere over the desert of the Australia on June 13, 2010, and landed safe on the ground after passing through the excessively high aerodynamic heat load with about 14 MW/m^2. All the component modules of the SRC have been recovered by June 15 (Fig. 1) . The present paper overviews the reentry operation and flight of the SRC together with post-flight analysis of the recovered heatshields together with the some results taken from the airborne radiation observation during the reentry.The post-flight analysis program is planned by 3 steps and is under progress : The first step is reconstruction of the reentry flight trajectory and the flight environment. The reentry trajectory is to be reproduced synthetically taking account of the accuracy of the reentry orbit determination, the SRC landing point, atmospheric density and the wind on the reentry day. And the second step is to overview the SRC through non-intrusive method such as X-ray CT-scanning. The linear absorption coefficient (LAC) distribution over the ablator material were successfully measured and converted to the density distribution based on careful correlation between X-ray CT scanning of the recovered heatshield and arc-heated test pieces (Fig. 2). The 3-dimensional laser-scanning has been also carried out for measuring the surface recession. Regardless of difficulty in the surface roughness, emissivity dispersion etc., 3-D surface has been numerically reconstructed and compared with the CAD data at the pre-flight. According to the airborne observation by JAXA 4-camera spectroscopic thermometry onboard DC-8, the surface temperature during the reentry was estimated to be 3400 K at maximum. The paper expands its discussion to the design validity of the thermal protection system of the Hayabusa SRC based on the results of the above post-flight forebody/aftbody heatshield impacted on the ground with the terminal velocity of 40m/s and 30 m/s, respectively. Nevertheless, the distortion at the ground impact seems to be severe and the gap between the two heatshield reassembled remained same as the designed before actual reentry flight. Precise measurement of the overall SRC shape by means of 3-dimensional laser scanning is described in the next section.

Fig. 1 Artist's Impression for Parachute Deployment and the Recovered 3 Components.

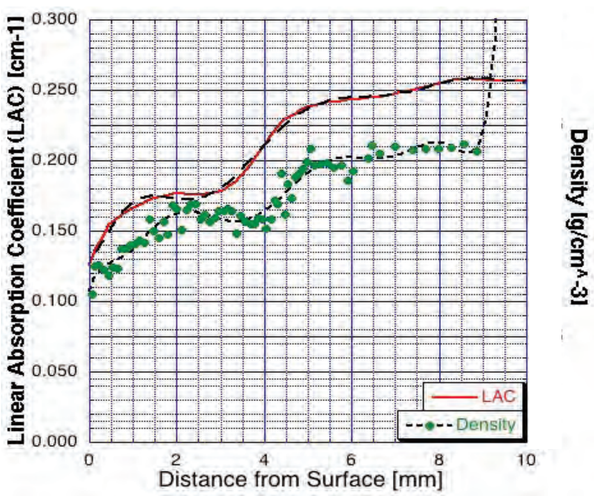

Fig. 2 Typical Example of the Density Distribution of the Recovered Hayabusa Heatshield

Multi-Mission Earth Entry Vehicle Development by NASA's In-Space Propulsion Technology (ISPT) Project

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The Planetary Science Decadal Survey, published in March 2011, includes several missions to return samples to Earth from around the Solar System. NASA's In-Space Propulsion Technology (ISPT) Project, funded by the Science Mission Directorate, is continuing to conduct activities that will mature Earth Entry Vehicle concepts for multiple missions. This work will provide an explanation of the Multi-Mission Earth Entry Vehicle (MMEEV) concept, context and benefits, and details of Fiscal Year 2011-12 activities, including impact foam testing, thermal soak modeling, and design tool development.

The current MMEEV maturation strategy is to advance critical vehicle characteristics to TRL5-6 before the next NASA Discovery or New Frontiers Announcement of Opportunity. The ISPT Project's funding level does not currently support a dedicated flight test prior to MMEEV use (nor has a flight test been conducted prior to other low-cost missions involving an EEV, like Stardust and Genesis). To assess vehicle designs for multiple missions, the Multimission Systems Analysis for Planetary Entry (M-SAPE) tool is being developed and improved at NASA-Langley. Parametric assessments of vehicles up to 2 meters in diameter, with a range of small payload masses (up to about 30 kg) can be conducted in a matter of hours, and the tool includes options for varying payload density and probe materials. In 2012, ground testing to validate M-SAPE models has begun. Ongoing activities include impact testing and thermal characterization of Rohacell foams, which inform both the structural response models and the thermal soak models in M-SAPE. The goal is to show how the probe will behave thermally after impact on Earth, and assess whether recovery timeline constraints or active thermal control are needed to meet certain mission requirements. Preliminary testing and analysis results will be used to identify other risk reduction activities and drive towards a nominal MMEEV design that can meet a variety of mission requirements.

PHOEBUS
a hypervelocity entry demonstrator

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ESA is today considering various missions, such as Marco Polo R and (Moon of) Mars Sample Return, requiring Earth re-entries at speeds up to 13 km/s.

To mature critical high speed re-entry technologies and consequently to quiken the development and reduce the development cost (and cost uncertainties) for future sample return mission, an in-flight technology demonstrator, named PHOEBUS (Project for a High-speed Of Entry Ballistic multi-User System), is presently under investigation at the European Space Research and Technology Centre (ESTEC) of ESA.

This paper focueses on the preliminary aerothermodynamics feasibility assessment conducted within the Concurrent Design Facility (CDF) study at ESA-ESTEC for the design of the PHOEBUS re-entry capsule starting from a parametric analysis of the entry phase to enable a preliminary design and a baseline configuration selection and concluded with non-equilibrium reacting flow computations coupled with radiation and transport simulations to estimate the heat flux experience by the TPS at few selected trajectory points. Mission analysis and preliminary concepts for capsule instrumentation will be also presented.

Re-entry Platform for In-flight Demonstration and In-situ Measurement

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The space politics tend to limit the lifetime of spacecraft in orbit by making compulsory the destructive re-entry for all of them after a certain period of time. Moreover, all the difficulties encountered in re-entry studies, the necessity of in-situ platforms for research in orbital decay and debris re-entry is needed to design correctly the future spacecraft and acquire more experience and knowledge in atmospheric re-entry. For these reasons and some others, the von Karman Institute for fluid dynamics (VKI) is responsible for the QB50 project, the first international constellation of nanosatellites for scientific and educational purpose. This challenging project focuses on studying the lower thermosphere with scientific payload for orbital and re-entry experimentations on different platforms.

Additionally to this project, the VKI will develop its own nanosatellite (presented in Fig. 1) in the frame of QB50 named Qarman (QubeSat for Atmospheric Research and Measurement on AblatioN) with a size of 34cmx10cmx10cm for a maximal mass of 3 kg derived from the CubeSat standard. The spacecraft is composed of a standard double-unit platform with sensors for atmospheric research and a functional unit for essential satellite operations as the other CubeSats. A third unit accommodating an ablative heat shield is added to protect the vehicle against the extreme aerothermal conditions expected during the re-entry. In addition of the proposed platform, a deorbiting system based on a drag augmentation device will permit to reach a large range of trajectories depending on its sizing. The objective of this mission is to conduct innovative in-flight experiments for re-entry study. The success of the mission is essential for VKI, allowing it to reinforce its expertise and knowledge in the field of re-entry. The comparison of the in-flight results with numerical simulations and ground test experiments will permit to assess methodologies for flight extrapolation of ground data and validation of models used for Thermal Protection System (TPS) design. The launch of the re-entry vehicle with the other nanosatellites of the QB50 project has been scheduled for June 2014. The demonstrator represents an ideal cost-efficient platform for re-entry flight test and validation of TPS materials and other payloads.

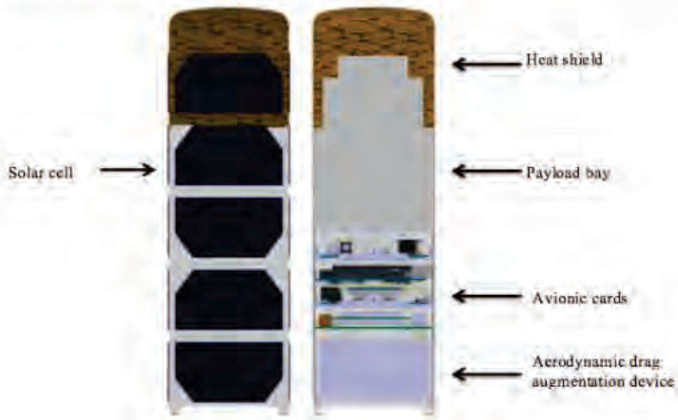

Figure 1: External and internal view of the CubeSat based re-entry platform

Orion Multi-Purpose Crew Vehicle Drogue Parachute Performance

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The Orion capsule is a critical element in NASA's Multi-Purpose Crew Vehicle program, intended to return four to six crew members, safely to Earth, on a return journey originating beyond Earth orbit. The Orion vehicle is modeled after the Apollo command module but is larger, more massive, and can handle more challenging entry conditions. A critical element of the Orion vehicle is the parachute subsystem. The three-parachute system includes two mortar deployed conical ribbon drogues, three ring-slot pilots, and three ring sail main parachutes. The system is derived from the Apollo architecture but subject to more challenging deployment conditions, peak loads, reliability requirements, separation events, and landing constraints. Although an extensive flight-test program is underway to measure performance of clustered and failure case scenarios, the system is always tested in the wake of a stream-lined forebody. A full-scale command module is too large to fit in a standard aircraft bay and a larger aircraft would be prohibitively expensive. As a result the effect of the blunt body wake on parachute drag and multi-body dynamics is not well quantified and heritage Apollo datasets do not encompass the Orion deployment space. To address this limitation, a subscale test program was conducted, focused on the performance of drogue parachute and capsule wake interaction. For the end-to-end parachute system, the drogue parachute is believed to be most sensitive to this fluid-structure-interaction environment due to the proximity to the forebody and the relative scale. For reference the projected diameter and trailing distance of the drogue is the same as the command module maximum diameter and only six diameters downstream.

The test configuration explored is a 10% scale command module with drogue parachute in a subsonic 3x2.1 m (10'x7') cross-section atmospheric wind tunnel. The test program utilizes non-intrusive diagnostics to provide a quantitative dataset of the wake and its interaction with the parachute flow-field. Specifically, particle image velocimetry (PIV) is used to measure the wake closure and three-dimensional velocity profile at multiple axial planes between the capsule and parachute, both with and without the parachute. A force balance is used to obtain aerodynamic forces and moments of the CM-parachute system. A single axis load cell is used to measure parachute drag. Nine high speed pressure transducers are used to obtain internal pressure measurements along three radials within the canopy. Static pressure ports are used to obtain pressure on the Orion heat-shield. High-speed video with a photo-grammetric reconstruction technique is used to measure the parachute dynamics including oscillation, trim, and inflation stability. The test program is intended to establish a new aerodynamic database for the Apollo-style drogue as a function of trailing distance, reefing ratio, pitch plane angle, and Reynolds number. This also represents the first measurement of internal pressure distribution for the Apollo conical ribbon drogue, leading to an improved understanding of the load distribution within the textile elements of the parachute.

Results to be presented include: (1) comparison is also made to full-scale drag and full-scale inflated shape, (2) frequency resolved parachute drag for all reefing stages, (3) parachute internal pressure with and without the CM wake, and (4) parachute dynamic motion. The test matrix maps out the deployment space in terms of dynamic pressure, pitch plane angle, and reefing stage.

The Small Payload Quick Return (SPQR) System as a Testbed for Future Planetary Probe Missions

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The SPQR is a proposed means of returning a temperature-controlled 4.5L payload canister from the International Space Station (ISS) in an on-demand fashion. In order to be compatible with ISS crew safety and internal processes, the de-orbit system uses an Exo-Brake drag device instead of other traditional propellant systems. Deployed from the ISS Japanese Experiment Module (JEM) air-lock, the controlled de-orbit sequence works in three stages. The first stage is the Exo-Brake initial de-orbit phase which lowers the system from the ISS orbit to an altitude of 100-130km. At this time, and depending on the state of the atmosphere (the exact point of release determines the targeting), stage 2 commences with the deployment of the 'hot' re-entry system. This is comprised of the Tube Deployed Re-entry Vehicle (TDRV) which is a self-orienting re-enty probe first tested on a sub-orbital flight in 2009. In the interior, the Phase Change Thermal Control Unit (PCTCU) payload canister is attached through a kinematic joint which minimize the conductive path into the payload. The third stage commences with the deployment of a GPS-controlled parafoil which delivers the payload to the intended target location. Of interest for use on small Mars 'Companion' missions, the TDRV permits a simplified Entry/Descent/Landing system due to the inherent design characteristics of a) self-orientation (and thus easy interface to the deploying spacecraft), and b) the low total heating due to the low ballistic coefficient and unique design. The use for earth entry at 7.6 km/s will allow the design to be fully studied and qualified for the more mild Mars direct atmospheric entry at ~6 km/s. The system is proposed for the Atromos Mars Mission or other surface investigations later in the decade.

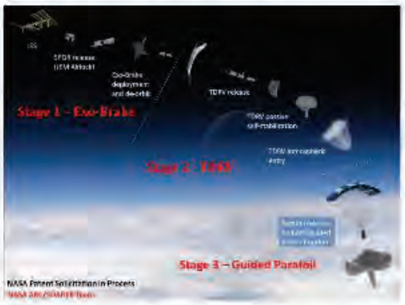

Fig. 1. The SPQR 3-stage atmospheric re-entry sequence.

Adapting Mars Entry, Descent and Landing System for Earth

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In 2001 - 2011 an inflatable Entry, Descent and Landing System (EDLS) for Martian atmosphere was developed by FMI and the MetNet team. This MetNet Mars Lander EDLS is used in both the initial deceleration during atmospheric entry and in the final deceleration before the semi-hard impact of the penetrator to Martian surface. The EDLS design is ingenious and its applicability to Earth's atmosphere is studied in the on-going project. In particular, the behaviour of the system in the critical transonic aerodynamic (from hypersonic to subsonic) regime will be investigated. This project targets to analyse and test the transonic behaviour of this compact and light weight payload entry system to Earth's atmosphere. Scaling and adaptation for terrestrial atmospheric conditions, instead of a completely new design, is a favourable approach for providing a new re-entry vehicle for terrestrial space applications.

The dynamical stability of the craft is analysed, concentrating on the most critical part of the atmospheric re-entry, the transonic phase, i.e. the phase when the speed of the vehicle is decelerated from hypersonic speeds to subsonic speeds. In Martian atmosphere the MetNet Lander's stability during this very turbulent phase is well understood and known. However, in the much more dense Earth's atmosphere, the transonic phase is much shorter and turbulence more violent. Therefore, the EDLS has to be sufficiently dynamically stable to overcome the forces tending to deflect the craft from its nominal trajectory and attitude. Due to the criticality of this phase most of the investigations in this study are focused to this regime. Once the scaling of the re-entry system and the dynamical stability analysis have matured enough, the preliminary design of the inflatable EDLS for Earth can be commenced. The scaled-down design model will be then put to wind tunnel tests, to verify performance of the design in the transonic phase.

The main objective is to provide a demonstrated and verified EDLS design for the entire relevant range of aerodynamic regimes expected to be encountered in Earth's atmosphere during the entry, descent and landing. Low Earth Orbit (LEO) and Lunar applications envisaged include use of the EDLS approach in return of payloads from LEO spacecraft, from the International Space Station and even from a Lunar base. The verified EDLS would also add an option for the design of European and Russian missions with applications in planetary surface exploration missions to other celestial bodies with significant atmospheres, such as Titan.

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 263255.

IR&D Studies of Light Weight Ablator for Future Reentry Capsule Heatshield

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Key Words: Reentry Capsule Heatshield Low-Density Ablator

Abstract

An IR&D (In-house Research and Development) effort is underway at IHI AEROSPACE Co., Ltd. to develop new lightweight ablators (hereafter abbreviated as LWA) for future reentry capsules. Current activities are focused on the development of LWA that is derived from the preform of Reticulated Vitreous Carbon (RVC) . This paper briefly introduces our effort.

IHI Aerospace Co., Ltd. is in charge of the heatshield of HAYABUSA reentry capsule, which successfully returned to Earth June 2010. With this success, HAYABUSA-2 project was authorized in JAXA (Japan Aerospace Exploration Agency) last year, which is planned and announced to be launched in 2015, and the CDR (Critical Design Review) was already over last December. The heatshield material is planned to be the same kind of CFRP (Carbon Phenolic) as used in HAYABUSA, that is to say, high density material of ρ=1.3g/cm3.

Now, our IR&D studies are being targeted towards post-HAYABUSA-2. We are currently striving to develop new type of LWA, that are still effective at extremely harsh conditions (heat flux level more than 10MW/m2). Therefore, our development activities focus on carbonaceous LWA. Although the basic research activities with regard to LWA have been extensively conducted in Japan for past several years, still we don't have the flight-proven LWA.

Upon developing a new type of LWA, we regard PICA (Phenolic Impregnated Carbon Ablator) as a benchmark material in the sense that it is widely characterized and also some of the basic properties are open to the public. According to the PICA-related patents, it is concluded that PICA-like material is supposed to a LWA derived from lightweight fired preform of ceramic fibers (including carbon fibers), impregnated with some kinds of thermosetting resin.

We started our IR&D study for LWA development, aiming at LWA derived from lightweight carbon preform impregnated with thermosetting resin. Therefore, LWA can be classified in terms of 3 features, such as (1) morphology of preform, (2) manufactured places of preform, (3) resin system to be impregnated. As listed in the followings, the possible combinations of LWA are considered to be 8 types, which is calculated from 2x2x2.

Morphology of Preform
- ✓ CBCF (Carbon Bonded Carbon Fiber)
- ✓ RVC (Reticulated Vitreous Carbon)

Manufactured Places of Preform
- ✓ Imported
- ✓ Domestic

Resin Type
- ✓ Phenolic Resin
- ✓ Polyimide Resin

Here, as for the polyimide resin system related technologies, we are permitted to take advantage of the technologies that are developed and originated in JAXA.

Upon development of LWA, we regard that it is indispensible to be domestic. The benefit of being domestic is summarized as follows.
- ✓ Cost Reduction (compared to imported materials)

Earth entry observations: Solution to inverse problem with incomplete data

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While the Earth orbits the Sun, it is subject to impact by smaller objects ranging from tiny dust particles and space debris to much larger asteroids and comets. To study these collisions in more details, and to better understand phenomena during hypervelocity atmospheric entry, we present a practical algorithm connecting ground based observations with the properties of otherwise unknown objects entering the Earth's atmosphere. In particular, we derive analytical dependencies between space object mass, its size and other properties from the rate of body deceleration in the atmosphere. The study is completed by considering luminosity of an object with the approach similar to (Gritsevich and Koschny, 2011)[1]. In addition, we highlight some directions for further studies and potential improvements to the proposed technique.

A Review of Apollo Splashdowns - Influence of Cavity Resurge on Stability

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Water landing offers a number of benefits for designers of space capsules - the oceans present a large area with essentially uniform mechanical properties, and the hydrodynamics of liquid impact generate largely tolerable loads given typical vehicle sizes and impact speeds, without having to include impact attenuation hardware such as airbags or retrorockets. These factors led to the selection of water impact as the nominal landing scenario for Apollo, which due in part to the better media coverage compared to Mercury and Gemini, has become the iconic 'splashdown'.

Some 9 of the 19 Apollo capsules that made splashdown in the open ocean (in addition to the crewed Apollo moon program flights, this includes several unmanned test flights, as well as the Skylab and Apollo-Soyuz Test Project flights) went into an inverted ('Stable II') orientation after landing. The wind and wave conditions associated with these inversions are summarized - all but one of the capsize events were in winds >6 m/s. The flight data are reviewed in the context of a series of ¼-scale-model tests performed in the mid-1960s at NASA Langley. A physical model is proposed for the dominant, but apparently hereteofore-unrecognized, mechanism of inversion, wherein the resurging central jet of the transient cavity catches the edge of the capsule under certain conditions of horizontal velocity and attitude and applies an overturning moment. This model explains how further increases of horizontal velocity in fact avoid capsize (as indicated both in scale model tests and in more recent numerical simulations of splashdown). The model is applied to the Orion capsule and to splashdown in Titan's hydrocarbon seas.

Session 7A: Airless & Primitive Bodies

M. Barucci: MarcoPolo-R: Asteroid Sample Return Mission

Asteroid sample return missions

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Most of information on asteroids comes (and will come for long time) from the ground-based observations, analyzing of the sunlight reflected by these objects. The current scenario of the asteroid population is necessary rough and lack of the details coming from "in situ" observations.

The space exploration of asteroids has been developed following a two-folds philosophy: missions of opportunity and dedicated missions. Concerning the former, missions Galileo, Cassini-Huygens, Stardust, Deep Space 1 and Rosetta successfully realized a total of seven fly-bys of main belt asteroids (including a binary system) on the way toward their main objectives. Up to now, the dedicated missions studied and realized to explore specifically one (or more) asteroid(s) have been NEAR-Shoemaker (one year in orbit around 433 Eros after a fly-by of 253 Mathilde), the technological mission Hayabusa (sample return from the asteroid 25143 Itokawa) and Dawn (still in orbit around 4 Vesta, and scheduled to continue its travel toward 1 Ceres and remain one year in orbit around it, starting in 2015). The first two realized the first landing on an asteroid (decided only at the end of the nominal mission) and the first asteroid samples return (even if only few micrograms were collected and stored in the return capsule) respectively.

In more than 20 years, only thirteen asteroids have been observed with the instruments on board of interplanetary spacecraft and each explored asteroid provides us with some "ground truth" to test the inversion techniques of the data obtained from ground based observations.

The challenge of the near future is to get asteroid samples back to the Earth, to complete the tools, which will allow us to have a significant improvement in the understanding of the nature of the small bodies population and consequently of the processes that presided the formation of planets.

In our poster we will outline the technical and scientific objectives of the three asteroid sample return missions currently under development (the Japanese Hayabusa 2, launch in 2014-15; the NASA New Frontier mission Osiris-Rex, launch in 2016) or feasibility study (the ESA Marco Polo-R, selection for a phase A study in 2013).

The European Lunar Lander: A Human Exploration Precursor Mission

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Introduction: ESA's Human Space Flight and Operations Directorate is continuing with preparations for its Lunar Lander project. The Lunar Lander is an unmanned precursor mission to future human exploration. This mission will enable the development of technologies, capabilities and scientific knowledge that will allow Europe to participate in future international exploration activities of the Moon and beyond.

The primary objective of the mission is to demonstrate soft precision landing with hazard avoidance and once on the surface it provides an opportunity for payload operations and scientific measurements. The scientific objectives for the mission have been established to address the major unknowns for future exploration activities.

The Lunar Lander is currently engaged in Phase B1 under the lead of the prime contractor Astrium GmbH (Bremen, Germany). Phase B1 includes mission definition, system and sub-system design and technology breadboarding activities, and shall be completed by autumn 2012.

Mission Architecture: The mission targets a launch in 2018 from Centre Spatial Guyanais, Kourou on a Soyuz launcher. The Lander will then be injected into a transfer orbit to the Moon by the Fregat upper stage and several weeks later will insert itself into a lunar polar orbit. The precision landing capability will then be applied to ensure a soft precise landing near the Lunar South Pole. The targeted landing sites are located at peaks where the high altitude relative to the surrounding topology, coupled with the slight inclination of the Moon's rotational axis, leads to extended periods of illumination.

Hazards and Illumination: A key factor in ensuring a robust mission design is a complete understanding of the illumination duration at the anticipated landing sites, the areas of the sites and the extent of surface hazards such as boulders, slopes and craters. To this end work is ongoing to fully characterise these aspects of the lunar surface in the areas around these peaks.

Scientific investigations: The scientific objectives that have been defined for the mission emphasise a number of key areas: the integrated dusty plasma environment at the surface of the Moon and its effects on systems; lunar dust as a potential hazard to systems and human explorers; potential resources which can be utilised in the future; and radiation as a potential hazard for human activities.

Conclusions: We report on the status of the European Lunar Lander mission and the ongoing work on the system design, technology development, and characterisation of potential landing sites.

Innovative Visual Navigation Solutions for ESA's Lunar Lander Mission

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Phase B1 of the European Lunar Lander (LL) mission was kicked off by the European Space Agency in 2010. The mission is aimed to autonomously, safely, softly and precisely land a spacecraft in the lunar South Pole region in the 2018 timeframe. Astrium, in charge of mission analysis and spacecraft design, is actively involved in the design of the GNC system for which innovative solutions had to be implemented in order to meet stringent landing requirements.

In frame of LL studies, Astrium had to identify the navigation solution that meets the stringent precision requirements derived from the expected size of the potential landing sites. Since IMU based propagation is not in line with required precision landing performances, it became necessary to develop a navigation solution that could improve estimation of s/c position and velocity in lunar reference frame. The selected navigation suite of sensors that should be used to achieve safe, soft and precision landing consists of an inertial measurement unit (IMU), a star tracker (STR), a distance to ground (DTG) sensor (radar altimeter or Laser range sensor) and a navigation camera. All sensor data is fused in a navigation filter.

Visual navigation was identified as key technology to meet the challenging requirements. During the course of the descent and landing trajectory, two main functionalities are required: (1) feature matching navigation based on known landmarks and (2) feature tracking navigation based on tracking of unknown features. After descent orbit initiation the spacecraft coasts from an altitude of 100 km down to 10 km. During this phase navigation is performed by sensor data fusion of feature matching, IMU and STR measurements. A feature point data base of known landmarks is generated in advance based on artificial generated images. Features extracted from the acquired image and their 3D correspondences taken from the data base are fed to the navigation filter. As the spacecraft moves closer to the surface, map errors associated to the reference DEM become significant and feature matching navigation is no longer reasonable. From the point when powered descent is initiated, images are used to perform feature tracking navigation. Since the shape of the terrain is not known a priori, many vision based navigation algorithms suffering from the scaling problem are not directly applicable. Astrium had to develop an approach which is completely independent of the terrain. Feature selection and tracking is implemented within the Feature Extraction Integrated Circuit (FEIC). Tracked points form the so called Optical Flow (OF) field. Rotational effects are discarded from the OF field which is then used to compute the velocity direction. The estimated velocity direction is combined with IMU and DTG sensor measurements in the navigation filter.

The paper describes the navigation concept of the Lunar Lander mission and focuses on vision based navigation (feature matching and feature tracking navigation). The functional operability is shown in terms of open-loop simulation results applied to the Lunar Lander trajectory using the full sensor suite including sensor fusion and filtering.

R. Garcia: Farside Explorer mission project and internal seismic structure of the Moon

FARSIDE EXPLORER MISSION PROJECT AND INTERNAL SEISMIC STRUCTURE OF THE MOON

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ABSTRACT

Farside Explorer is a proposed Cosmic Vision medium-size mission to the farside of theMoon consisting of two landers and an instrumented relay satellite. The farside of the Moon is a unique scientific platform in that it is shielded from terrestrial radio-frequency interference, it recorded the primary differentiation and evolution of the Moon, it can be continuously monitored from the EarthMoon L2 Lagrange point, and there is a complete lack of reflected solar illumination from the Earth. Farside Explorer will exploit these properties and make the first radio-astronomy measurements from the most radio-quiet region of near-Earth space, determine the internal structure and thermal evolution of the Moon, from crust to core, and quantify impact hazards in near-Earth space by the measurement of flashes generated by impact events. The Farside Explorer flight system includes two identical solarpowered landers and a science/telecommunications relay satellite to be placed in a halo orbit about the EarthMoon L2 Lagrange point. One lander would explore the largest and oldest recognized impact basin in the Solar Systemthe South PoleAitken basinand the other would investigate the primordial highlands crust. Radio astronomy, geophysical, and geochemical instruments would be deployed on the surface, and the relay satellite would continuously monitor the surface for impact events.
A review of our current knowledge of the internal seismic structure of the Moon is also presented. Error bars and limitations of current internal structure models of the Moon are discussed.

Key words: LaTeX; ESA; macros.

Figure 1. Relevance of Farside Explorer mission to cosmic vision science objectives.

1. FARSIDE EXPLORER SCIENCE OBJECTIVES

The relevance of Farside explorer mission project to ESA Cosmic Vision science objectives is highlighted in table 1. The science objectives of Farside Explorer are conceived to exploit the unique environment offered by the farside hemisphere of the Moon. Three primary investigations are dictated by the properties of this platform.

2. A REVIEW OF INTERNAL SEISMIC MODEL OF THE MOON

The internal seismic models of the Moon obtained from Apollo data are presented from the upper few hundred meters down to the core. Error bars and limitations due to past seismic deployments are quite important. Their influence on our current knowledge are discussed. Synergies between past and future seismic observations are also highlighted.

Application of Simultaneous Localization and Mapping algorithm to Terrain Relative Navigation for Lunar Landing

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Future Exploration Missions to the Moon envisage tight constraints in landing conditions allowing a safe and precise landing in near polar lunar regions. Ongoing developments make use of surface-relative navigation algorithms which elaborate visual observations in order to estimate the state of the spacecraft during descent.

Methods based on pure optical observations allow to enhance the performance of the navigation system with a very limited increase of complexity, weight and power requirements.

Astrium Space Transportation developed, within the Inveritas Research Project workframe, a set of solutions for Terrain Relative Optical Navigation which are mainly based on standard algorithms from the Robotics and Computer Vision communities applied to a Lunar Landing scenario.

This work focuses on an application of a Simultaneous Localization and Mapping algorithm able to correct the estimates of the spacecraft state and estimate 3D position of features in its surroundings during the last phase of the landing.

A first image processing algorithm tracks features along flight and inputs their observed values in the field of view of the camera into an optimal state estimation algorithm (Extended Kalman Filter) where such observations are coupled with inertial measurements and measurements coming from a Distance to Ground Sensor.

The algorithm estimates the feature locations on the surface of the terrain and provides spacecraft state relative to such features. While the unknown position of the features in a global coordinates frame does not allow to recover full state estimation, the algorithm aims to be a reliable velocity estimator and to estimate range to feature information.

The results of this navigation concept show to be promising and allow to meet safe and precise landing requirements.

A low cost penetrator mission to study lunar volatiles

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The possibility that water and other volatiles are present within permanently shaded craters at the lunar poles has increased very considerably following the observations of recent Lunar missions. However, an insitu confirmation and follow-up study remains to be made. Measurement within such very low temperature environments is particularly difficult and the absence of available sunlight adds additional problems for any rover based approach.

We propose here a very low cost, single shot, short duration penetrator based mission which has the objective of confirming (or otherwise) the presence of water or volatiles. The mission would be appropriate to a European Space Agency Small Mission. The feasibility of penetrators in general comes from both earlier mission developments and an ongoing programme of studies and trials being conducted in the UK, currently under an ESA grant. These studies are directed at a Europa application which, in some ways, is similar to the environment in lunar shaded craters. Recent developments suggest that a short duration mission (a few hours of operation beneath the lunar surface) is both feasible and scientifically credible.

We will present an outline of the mission concept, its elements, science payload and operations.

A SIMPLE, ROBUST AND ADAPTABLE STRATEGY FOR BALLISTIC LANDINGS ON SMALL BINARY BODIES

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ABSTRACT

We present a strategy that allows a spacecraft to safely deploy unpowered landers to small bodies with minimum requirements. Using the natural features of the restricted 3-body problem, we show how ballistic deployments are especially indicated for reaching the surface of the secondary asteroid of a small body binary. We establish a deployment strategy and discuss its high robustness to GNC errors and uncertainties. We then prove that this strategy can be applied for exploring the vast majority of small body targets.

Key words: asteroid; NEO; small bodies; binary; deployment; landers; R3BP.

1. INTRODUCTION

The study of small bodies, such as asteroids and comets, has become a topic of great interest for solar system science in the last two decades, with for instance the mission NEAR-Shoemaker in the 90's, and more recently Hayabusa and the ongoing Rosetta mission. It is reasonable to assume that a future mission will eventually aim at investigating a binary asteroid, with the possible objective of deploying landers on the surface of both asteroids. Previous analyses of binary orbiters have already been carried out[BS08, FDHS10, SB05]. The present paper describes a strategy for ballistic landings onto the surface of asteroids in a binary system, generalizing a previous work done in this field[TS11]. The choice of ballistic trajectories will allow for unpowered and blind landers, jettisoned from a mothership in appropriate conditions that would yield to a landing.

We use the model of the Circular Restricted 3-Body Problem (CR3BP), applied to an asteroid binary system. In this model, two asteroids, a primary (biggest) and a secondary (smallest), are orbiting each other in a perfectly circular orbit, by the laws of Keplerian mechanics. The third body – here a spacecraft or a lander – is supposed to have no influence on the others, and is subject to the point-mass gravity of the asteroids. Throughout this paper, to illustrate the presented strategy with precise figures and practical considerations, we will use as example the asteroid system 1999 KW4 which characteristics are presented on Table1.

Table 1. Relevant information on 1999 KW4, nominal values, from Ostro et al.[Oa06]

	Parameter	Value
Alpha	Largest Axis	1532 m
	Intermediate Axis	1495 m
	Shortest Axis	1347 m
	Mass	2.353×10^{12} kg
	Rotation Period	2.765 m
Beta	Largest Axis	571 m
	Intermediate Axis	463 m
	Shortest Axis	349 m
	Mass	0.135×10^{12} kg
	Rotation Period	17.42 h
Mutual Orbit	Semi-Major Axis	2548 m
	Mass Fraction (μ)	5.43%
	Period	17.42 h

2. DEPLOYMENT FROM LAGRANGE POINTS

We recall the equation of the CR3BP. These equations are usually set in a rotating frame, which makes the system autonomous: the $\hat{\mathbf{x}}$ axis is pointing from the primary body to the secondary; the $\hat{\mathbf{z}}$ axis is along the mutual orbit normal; the $\hat{\mathbf{y}}$ axis completes the trihedron and is therefore aligned with the velocity of both bodies in a (quasi-)inertial frame. The units are also normalized into Jacobi units: the distance between the primary and the secondary centers of mass becomes the unit of distance; the sum of the two masses becomes the unit of mass; eventually the unit of time is set so that the universal constant of gravitation has value 1, or equivalently so that the angular velocity of the binary system is 1. We note μ the mass fraction of the system (i.e. the mass of the secondary in Jacobi units), r_1 the distance from the spacecraft to the primary body and r_2 its distance to the secondary body.

In these frame, units and notations, the equations of mo-

Lander Concepts for MarcoPolo-R

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MarcoPolo-R is an asteroid sample return mission, proposed to ESA's Cosmic Vision Programme. The mission is currently in the assessment study phase of the M3-class mission competition.

The main scientific objective of MarcoPolo-R is to return a sample from a primitive asteroid (current baseline is the binary asteroid 1996FG3) back to Earth, unaltered by the atmospheric entry process or terrestrial weathering, to allow detailed analysis with state of the art laboratory equipment.

Certain aspects, however, have to be determined in-situ. Most prominently, these are (a) context measurements, (b) physical properties, before the sampling process and (c) the global characteristics of the asteroid. In order to address these scientific objectives, two designs of landers (both based on the currently developed MASCOT platform, part of the Japanese Hayabusa 2 mission) are currently studied.

One Lander Design, MAPOSSI, under science lead at DLR (Berlin) will focus on analytical measurements and include a Laser Induced Breakdown Spectrometer (LIBS) as well as an Alpha Particle X-Ray Spectrometer (APX), IR-imaging spectrometer, a radiometer and a camera (tbc), another, FANTINA, under scientific lead at IPAG (Grenoble) includes a radar tomographer and is aiming at providing the 3D internal structure of the asteroid.
Additional in-situ instruments (e.g. a magnetometer and a mass spectrometer) are studied in parallel, and may be considered as optional payload for any surface element selected for the MarcoPolo-R mission.

MERLIN: Mars-Moon Exploration, Reconnaissance and Landed Investigation

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Mars' moons Phobos and Deimos have albedos, spectra and densities resembling D-type bodies, a class of objects common in the outer solar system but rare in the inner solar system [1-3]. D-type objects are widely hypothesized to be "ultraprimitive", rich in organics and volatiles [4], but their true composition is uncertain and volatile-poor compositions are also consistent with remote measurements [5]. Phobos and Deimos offer a unique opportunity to investigate D objects and the evolution the Mars system with a high science payoff, low-risk inner solar system mission.

The Mars-Moon Exploration, Reconnaissance and Landed Investigation (MERLIN), a Discovery-class mission concept, targets Deimos, where it will investigate the processes that have shaped a D-type body and test models for the composition of this spectral class of small bodies. MERLIN addresses NASA science goals and collects information on Deimos' surface valuable to the planning of future human exploration of the Mars system, during an orbital reconnaissance phase followed by a landed phase when a MER-like arm deploys contact instruments to the surface. The orbital measurements put the landed science into context and investigate the processes that have shaped small, D-type bodies. Following Mars Orbit Insertion (MOI) MERLIN executes trajectory correction maneuvers to fly nearly in formation with Deimos, completing about 5 months of global mapping and radio science measurements. A landing site on fresh material exposed in an albedo streamer is characterized and certified as safe for landing. The spacecraft descends to the surface and conducts landed measurements. The instrument complement and operations largely derive from hardware and ground systems proven on MER, MRO and MESSENGER. During the orbital phase, a multispectral wide-angle camera (WAC) and high-resolution narrow-angle camera (NAC) based on MESSENGER/MDIS determine Deimos' geology, surface properties, and shape, while radio science probes the interior. After landing, a MER-like arm accurately deploys an alpha particle X-ray spectrometer to measure elemental composition, a Raman spectrometer [6] to measure mineralogic com-position, and a color microscopic imager to determine regolith texture. An operational stereo camera (OpsCam) and a terrain-imaging camera (TerrainCam), based on MER's Hazcam and Navcam, support tactical planning of landed measurements and characterize geology of the landing site. MERLIN is implemented by the Applied Physics Laboratory, together with its partner institutions the Jet Propulsion Laboratory and Washington University in St. Louis.

References: [1] Grundy, W. M. et al. (1991) Aseteroids, Comets, and Meteors 1991, 215-218. [2] Murchie, S. and S. Erard (1996) Icarus, 123, 63–86. [3] Rivkin, A. S. et al. (2002) Icarus, 156, 64-75. [4] Hiroi, T. et al. (2001) Science, 293, 2234-2236. [5] Emery, J. and R. Brown (2003) Icarus, 164, 104. [6] Kong, W.G. and A. Wang (2010) LPSC 41, abstract #2730.

Roadmap for and potential science return of a Europa Lander Mission

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and the Europa Science Definition and Technical Teams.

Our recent study that investigated the challenges and scientific return involved in placing a lander on the surface of Jupiter's moon Europa. Europa is one of the most attractive astrobiological targets in the solar system. Assessing Europa's habitability requires understanding whether it possesses the three "ingredients" for life: water, chemistry, and energy. NASA recently enlisted a small Europa Science Definition Team (ESDT) and a corresponding joint JPL/APL technical team to consider Europa mission options feasible over the next decade, compatible with NASA's projected planetary science budget and addressing the high science priority set by the Planetary Decadal Survey. The teams studied three Europa mission concepts with an overarching goal to "Explore Europa to investigate its habitability." Each mission would address this goal in complementary ways, with high science value of its own.

One option, a Europa lander, would address three key objectives for Europa: (1) *Composition:* Understand the habitability of Europa's ocean through composition and chemistry, (2) *Ocean and Ice Shell:* Characterize the local thickness, heterogeneity, and dynamics of any ice and water layers, and (3) *Geology:* Characterize a locality of high scientific interest to understand the formation and evolution of the surface at local scales. The ESDT assessed investigations and measurements to achieve these objectives, and the Europa technical team has developed an implementation approach to accomplish them.

The nominal mission concept includes a carrier element and a lander module. The carrier element is designed to deliver sufficient lander wet mass to low Europa orbit, enable pre-landing reconnaissance imaging, and act as a telecom relay for the lander. The carrier element is a 3-axis stabilized, single fault-tolerant bus powered by 2 ASRGs and a 30Ah battery, with an 890N Bi-prop main engine with Monopro thrusters for attitude control, and an X/Ka-band 3.0 m fixed High Gain Antenna and UHF relay. The carrier includes a reconnaissance imager and utilizes a nested shielding approach to reduce the radiation risk from the challenging Jovian radiation environment. The lander element is designed to be robust in order to maximize the probability of mission success. During landing it utilizes 3-axis-stabilized monopropellant thruster-based attitude control and employs a hazard detection system. It accommodates the science payload and a sampling system with drill. A preliminary model payload would consist of a mass spectrometer, Raman spectrometer, magnetometer, multi-band seismic package, a site imager, and a microscopic imager. The model payload includes the ability to sample pristine materials at shallow depths to identify endogenous vs. exogenic (and radiation-derived) materials. To maximize the mission duration, the lander concept would land on lower radiation regions of the surface (outside of the trailing hemisphere), where modeling suggests radiation drops by an order of magnitude.

The spacecraft would nominally launch in 2021 on a Delta IVH, undertaking a 6.4-year VEEGA trajectory leading to Jupiter Orbit Insertion in 2028. After a pump-down phase lasting 1.4 years, the spacecraft system would enter Europa orbit in 2029. Because so little is known about Europa's surface at lander scale (meter-scale or better), the spacecraft would spend 1 month in orbit acquiring high-resolution imaging data of a set of targets preselected on the basis of Galileo images, in order to allow the most viable candidate landing site to be selected for landing.

Once the landing site has been identified, the lander spacecraft would be deployed from a 200x5 km orbit, after which the carrier element would return to a 200x200 km orbit to act as a telecom relay. Following separation, the lander element would descend to the surface using a stop-and-drop process, performing a solid rocket motor deorbit burn to remove most of its orbital velocity. The remainder (probably less than 10%) of its velocity is removed by use of the spacecraft's monopropellant thrusters. During descent, the lander element would carry out terrain relative navigation and hazard avoidance allowing the spacecraft to descend to a safe landing site for soft touchdown at ~0.5 m/s. Once on the surface, science measurements would be carried out for a minimum of one Earth month (about 9 Europa orbits, or eurosols).

An astrobiology Payload Complement for a Europa Penetrator

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We report on the selection and design of an astrobiology payload for a Europa penetrator, which would impact at ~300m/s, and subsequently access a sub-surface sample, analysis it, and return the science data to an overflying orbiter.

We aim for a very highly integrated package whose payload elements are limited to 2.2 kg before 50% maturity margin for elements with TRL<5, and a further 20% system margins are applied. This mass limit also has to include a sample acquisition mechanism.

Selection of instruments requires that the astrobiology return is maximised with technology which is capable of flight readiness by the end of this decade. In the case of absence of astrobiological signatures the associated geophysical return is also assessed. Major drivers used in instrument selection and design are science capability within a penetrator context, and technology elements which include resources (mass, power, volume), maturity (heritage, TRL), ruggedness, contamination, radiation, planetary protection, mounting orientation, thermal, telemetry and commanding issues.

Design of an Astrobiology Penetrator and Delivery System

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Planetary penetrators are hard landers, designed to survive a high-g impact into a planetary body and operate from the subsurface. The concept is well established. The Japanese Lunar-A probe, the Russian Mars-96 and NASA's Mars Polar Lander concepts all included penetrators of various sizes and complexities. Sadly none achieved mission success due to cancellation, launch failure and loss of contact respectively.

The proposed UK MoonLITE mission planned to deliver four penetrators to the Moon's surface, with a concept successfully trialled in impact testing in the UK, however the budget for implementation was not available. Subsequently penetrators were studied in the context of the joint ESA/NASA 'Europa Jupiter System Mission' concept (EJSM) which was baselined to visit the Jovian system. The Penetrator Phase 1 ESA study in 2010 concluded that it was feasible to deliver a penetrator with a seismology-oriented payload to the surface of Europa but that key developments were required to develop the technology and mitigate risk.

This paper will present the mission and system design for a more advanced astrobiology penetrator which is the focus of the current Penetrator Phase 2 ESA study. A high level of payload and platform integration is a key design goal of this study and full system-level impact testing of breadboard penetrators are also planned. The target focus for this project is also Europa, with applicability for Mars also addressed. Europa is considered a potential candidate for harbouring life, with hints of a warm subsurface ocean directly interfacing with a rocky core. The temperature-stable and radiation shielded environment beneath the ice crust presents a potential haven. The Martian subsurface is also unknown and considered a Planetary Protection special region; the oxidation-free subsurface environment may also show signs of past or present biological activity. In either case, direct contact with the interior provides an ideal interface to monitor geological act0ivity and collect pristine samples. Reflecting this, the required payload concept is aimed at astrobiology with a subsurface sampling mechanism.

Session 7B: Cross-Cutting Technologies II

R. Trautner: ESA supported Chip and ASIC Technology Developments for Exploration Missions including Planetary Probes

ESA supported Chip and ASIC Technology Developments for Exploration Missions including Planetary Probes

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Exploration Missions including Planetary Probes are among the most resource-constrained types of space missions. The achievement of minimized mass, power and size for avionics elements and payloads is a key factor for optimizing spacecraft performances and ultimately for achievement of maximized scientific output. For the miniaturization of avionics and payloads the development of highly integrated components is required. In this area, the integration of both analogue and digital circuitry on the same semiconductor chip is a powerful technique for minimizing size and power consumption, while at the same time achieving increased component reliability. For example, the integration of a complete data acquisition and processing chain (consisting of analogue frontend elements, multiplexer, A/D converter, one or more digital signal processors, memory buffers, general purpose processor with fast digital links and – if required – D/A converter, PWM outputs, General Purpose I/O, slow HK data acquisition with multiplexer etc.) can shrink the size of a dedicated printed circuit board to little more than the footprint of a single chip, and allow the implementation of performant instruments or subsystems within mass constraints that would otherwise be impossible.

Furthermore, many types of missions like those visiting Jupiter or the Sun require high levels of radiation hardness that are not provided by commercial or even standard space qualified components.

In order to address the needs for mixed signal chip developments, high radiation hardness, and adequate performance of components, ESA has been supporting a range of ASIC technology developments in the past years [1], including the Design for Radiation Effects (DARE) library [2, 3]. Based on these ASIC technologies, prototype chips are being developed that will demonstrate fast A/D, D/A, microprocessor and digital signal processor functionalities that can be used as building blocks for future space qualified mixed signal components.

In this paper we will first address the importance of radiation hard, mixed signal, performant components with low power consumption for the miniaturization of spacecraft avionics and payloads. ASIC technology developments that support integration of analogue and digital components on-chip with a radiation hardness of up to 1 Mrad will be introduced. Prototype components for the demonstration of analogue elements, fast and slow A/D and D/A converters, digital signal processor cores, network on chip elements, hardened memories and other elements will be presented that can be combined to form large mixed signal systems on chip for dedicated space applications.

Plans for the development of components based on the described technologies and IP building blocks are outlined, and possible applications for planetary probes are discussed. The maturity and expected future evolution of the underlying ASIC libraries is explained.

[1] ESA Microelectronics website, http://www.esa.int/TEC/Microelectronics/SEMSTCV681F_0.html

[2] The Design against Radiation Effects (DARE) Library, http://microelectronics.esa.int/finalreport/DARE-Presentation.pdf

[3] DARE Final Presentation and User Forum Day papers, http://microelectronics.esa.int/dare/15-Feb-2011/

NASA Space Communications and Navigation Support to Planetary Probe Missions

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In 2006 The National Aeronautics and Space Administration (NASA) formed the Space Communications and Navigation (SCaN) office with the charter of integrating NASA's space communications capabilities into one seamless system. SCaN has recently emplaced an architecture for this "Integrated Network." The Integrated Network will comprise the assets of the Deep Space Network (DSN), the Near Earth Network, and the Space Network (which includes the Tracking Data Relay Satellite System). Users of the Integrated Network will be able to plan support services using a integrated service portal, providing the same planning and service interface for all of SCaN's network capabilities.

Since the DSN is a critical piece of many planetary probe missions, the plans for the Integrated Network are of interest to this community. As implementation of the Integrated Network progresses, NASA will continue to engage this and other science mission communities to ensure the appropriate services are maintained and that the service interfaces are made easier and more streamlined. This paper, which may be viewed as part of this engagement, explains the overall plan for the Integrated Network, the top-level plans for its component capabilities, and the goals for the interfaces between the Integrated Network and the mission community.

In parallel with the development of the Integrated Network, NASA has instituted several new policies and guidelines concerning the use of the various SCaN assets. These are intended to help mission designers plan appropriate and efficient use of Integrated Network assets. An example is the guidance for the use of single DSN 34m antennas for routine deep space mission operations. There has been some confusion over these policies and guidelines. This article is meant to help mission designers understand them as well as the rational behind them.

Development and Testing of a Maneuverable Subsurface Probe That Can Navigate Autonomously Through Deep Ice

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Extensive water ice bodies exist on Mars, Europa, Enceladus, and other moons in the outer solar system. Although their subsurface environments are scientifically extremely interesting, they are also extremely difficult to access. Europa is probably most interesting from the astrobiological perspective, but access to subsurface material is easier on Enceladus. Recent analyses of Cassini measurements imply a subsurface salt-water reservoir on Enceladus, where ice grains containing organic compounds escape via cryvolcanism from "warm" fractures in the ice, known as "Tiger Stripes" [1]. Because landing in close vicinity to such a fructure is too risky, we propose to land at a safe distance and to use a maneuverable subsurface ice probe to navigate to such a water-bearing fracture at a depth of ~200 m below the surface. Once there, the subsurface ice probe can sample and analyze the materials in the fracture. The required technology is currently developed and tested at FH Aachen University of Applied Sciences' Astronautical Laboratory. "IceMole" is a novel maneuverable subsurface ice melting probe for clean sampling of ice and subglacial liquids and for clean in-situ measurements [2]. A first prototype was successfully tested on the Swiss Morteratsch glacier in September 2010 and demonstrated successful horizontal, upward and downward melting capabilities for distances up to ~5 m. A driving curve with a ~10-m radius and the penetration of a ~4-cm dirt layer was also achieved.

Funded by the German Space Administration (DLR), a university consortium, led by FH Aachen, currently develops a much more advanced IceMole probe, which includes a sophisticated system for obstacle avoidance, target detection, and navigation in ice. The main technical objective of this project, which is termed "Enceladus Explorer" (or "EnEx"), is to develop and test the technology that is required for navigation in deep ice, in preparation of the IceMole and the associated navigation technology for Enceladus and other potential extraterrestrial targets. The EnEx-probe will also feature a clean mechanism for the sampling of subglacial brine from a crevasse. To validate the technology, we intend to use the EnEx-probe for clean access into a unique subglacial aquatic environment and an extraterrestrial analog in the McMurdo Dry Valleys, Antarctica, known as Blood Falls; with subsequent sample return from this subglacial brine for chemical and microbiological analysis [5,6].

In our conference contribution, we

1) describe the IceMole design and report the results of the field tests of the first prototype on the Morteratsch glacier,
2) describe the Enceladus Explorer mission concept, including the developed probe and navigation solution

References:

[1] F. Postberg, J. Schmidt, J. Hillier, S. Kempf, R. Srama. A salt-water reservoir as the source of a compositionally stratified plume on Enceladus. *Nature*, 474:620–622, 2011.
[2] Wikipedia: IceMole.
[3] A. Mann. The IceMole cometh. *Nature News*, 2010.
[4] B. Dachwald, C. Xu, M. Feldmann, and E. Plescher. Development of a novel subsurface ice probe and testing of the first prototype on the Morteratsch glacier. In *Geophysical Research Abstracts*, volume 13, 2011. EGU2011-4943.
[5] J. A. Mikucki and J. C. Priscu. Bacterial diversity associated with Blood Falls, a subglacial outflow from the Taylor glacier, Antarctica. *Applied and Environmental Microbiology*, 4029–4039, 2007.
[6] J. A. Mikucki, A. Pearson, D. T. Johnston, A. V. Turchyn, J. Farquhar, D. P. Schrag, A. D. Anbar, J. C. Priscu, and P.A. Lee. A contemporary microbially maintained subglacial ferrous "ocean". *Science*, 324:397–400, 2009.

Investigating the Composition of Enceladus via Primary Lander and Underwater Microorganism Explorer (ICEPLUME)

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Investigating the Composition of Enceladus via Primary Lander and Underwater Microorganism Explorer (ICEPLUME) is a proposed mission to Enceladus originating from an undergraduate senior design class. The motivation for the project comes from Enceladus' promising outlook for the discovery of astrobiology in our Solar System. ICEPLUME consists of an orbiter, lander, and ice-penetrating probe all encapsulated within an aeroshell for interplanetary travel.

This mission is unique in a number of techniques and technologies. The propulsion to Saturn starts with a series of flybys coupled with solar electric propulsion (SEP), composed of solar panels and ion thrusters. The mission trajectory then arrives at Titan, where the spacecraft performs an aero-gravity assist maneuver to utilize atmospheric drag for velocity reduction. Due to Enceladus' small diameter (approximately 500 km), insertion into a circular science orbit demands a large drop in velocity. An aero-gravity assist maneuver, series of flybys and chemical burns enable final orbit insertion.

The intense heat loads generated by the aero-gravity assist maneuver necessitates a heat shield and backshell to protect the orbiter, lander, and probe. The physical in-transit configuration of these components is therefore greatly constrained to fit within the aeroshell. ICEPLUME is proposing the largest aeroshell ever flown and therefore requires lower material densities in order to keep the mass of the entire system below the mass of fuel consumed using only chemical burns. Additionally, with its longer backshell length, the aeroshell must split along the axial plane as well as the radial plane in order to prevent the orbiter from damage during deployment.

Once in orbit around Enceladus, the lander descends down to the surface, where it deploys the ice-penetrating probe. The lander acts as a communication relay between the probe and orbiter containing minimal science instruments. The probe houses science instruments to investigate the composition of the ice as it descends beneath the surface of Enceladus towards the proposed subsurface ocean.

The orbiter has a heritage design similar to Cassini, equipped with science instruments to satisfy science goals outlined by NASA-JPL in the "*Analysis of Architectures for the Scientific Exploration of Enceladus*".

ROBUST AND AUTONOMOUS AEROBRAKING STRATEGIES

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The growing interest of the European Space Agency in aerobraking as a mission enabling technique is testified by the fact that several exploration missions currently envisage this technique in their baseline scenario (Exomars, Mars Sample Return Orbiter, NetLander). Since aerobraking is a technique that has never been experimented in past European missions, ESA has fostered the investigation on mission operations approaches and GNC strategies by financing several R&D projects. Among these, the Robust and Autonomous Aerobraking Strategies (RAAS) represents an important attempt to tackle this technique systematically and with a realistic approach to real operations planning.

The main goal of RAAS is to investigate mission operations and GNC strategies for both S/C attitude and pericentre altitude control, fulfilling at the same time specific autonomy and robustness requirements. The analysis is performed for the reference mission Mars Sample Return Orbiter (MSRO).

From the point of view of pericentre altitude guidance, an innovative approach has been introduced consisting of corridors automatically adapting themselves to the changing geometry of the orbit. Both 1-D and 2-D control corridor definitions have been formulated in this respect.

From a point of view of mission operations, an innovative approach has been proposed enabling S/C autonomies of up to one week. To this end, an onboard PTE (Pericentre Time Estimator) algorithm has been introduced to avoid too frequent in-orbit timing sequence updates and a precise ground and onboard operations schedule has been defined for two different autonomy levels.

Moreover, in order to increase the robustness of the corridor control, an atmosphere estimation strategy has been experimented, which is based on the use of an onboard heat flux sensor. Measurements of either the heat flux at pericentre or the heat load per drag pass are compared with their predicted values to evaluate a scale factor. Such scale factor is applied to the reference atmosphere model to predict the values of the control variables in future orbits, thus adapting to rapidly changing atmosphere conditions; e.g. dust storm scenarios.

The operations approach described above clearly requires specific GNC algorithms to command the S/C attitude changes on a 1-orbit time scale, and an autonomous GNC mode management compliant with an autonomy of several days. The S/C must switch from vacuum attitude control to drag pass attitude control and vice-versa every orbit, and when a manoeuvre is planned, it must re-orient itself parallel to the required ABM direction. Therefore, the RAAS poject has also investigated GNC algorithms covering both normal operational and safe modes, implementing, at the same time, FDIR strategies to comply with potentially very stringent planetary protection requirements.

Finally, the results of the validation campaign for this overall GNC approach are provided, together with some inputs for a roadmap of European aerobraking activities.

Low-Density Supersonic Decelerator Technology Demonstration Mission

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The Low-Density Supersonic Decelerator (LDSD) Technology Demonstration Mission is now almost two years old. We will discuss the trials and tribulations of planning and implementing a complex technology development project, the progress to date in the development of the technologies, the successful operation of a new outdoor wind tunnel system using rocket sleds, and the road ahead for LDSD.

1. Jet Propulsion Laboratory, California Institute of Technology

Development and Testing of a New Family of Low-Density Supersonic Decelerators

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Abstract—The state of the art in Entry, Descent, and Landing systems for Mars applications is largely based on technologies developed in the late 1960's and early 1970's for the Viking Lander program. Although the 2011 Mars Science Laboratory will make advances in EDL technology, these are predominantly in the areas of entry (new TPS and guided hypersonic flight) and landing (a sky crane architecture). Enabling increases in entry and landed mass beyond MSL will require advances predominantly in the field of supersonic decelerators. With this in mind, a multi-year program has been initiated to advance three new types of supersonic decelerators that will enable future large-robotic and human-precursor class missions to Mars.

Increases in entry mass of ~30% above MSL are possible with the present stable of medium-class launch vehicles. However, only marginal increases in aeroshell size may be possible, thus leading to large increases in ballistic coefficients. To take advantage of the increase in entry mass that is possible, two key improvements are needed. First, supersonic decelerators must be developed that can be utilized at Mach numbers and dynamic pressures greater than those allowable with the Viking-heritage Disk-Gap-Band parachute. Second, a new family of parachutes must be developed that will bring the increased masses to suitable terminal descent staging conditions. An objective of the Low Density Supersonic Decelerator (LDSD) program is to bring to TRL-6 a 6 m diameter attached torus inflatable aerodynamic decelerator (IAD) and a 30 m diameter supersonic Ringsail parachute. The combination of these two technologies would enable future missions to maximize the launch vehicle capability of an Atlas V rocket, deliver in excess of 1100 kg to an elevation of 1km MOLA, and provide considerable improvements in the landed accuracy of the system.

With an eye towards human-precursor missions, and the even larger entry masses that they will require, the LDSD program will also advance to TRL-5 a second, larger IAD of ~10 m in diameter. Maturation of such an IAD, in combination with the large Ringsail parachute, will enable future missions to maximize the capacity of a Delta IV-H or similar launch vehicle.

The goal of this paper is to provide a review of the analyses that were performed in support of decelerator down-selection and details on the development and testing that will be required to mature them. The results of a large trade study of multiple IAD and parachute types and sizes will be summarized. The paper also provides a review of the test program necessary to mature these decelerators.

Fluid-Structure Interaction Analyses of a Tension Cone Inflatable Aerodynamic Decelerator

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Computational fluid-structure interaction (FSI) analyses may play a signifant role in the design of inflatable aerodynamic decelerator (IAD) systems and in their qualification for flight missions. FSI analyses can provide initial aeroelastic deflection and stress predictions that can be incorporated into the design process. FSI analyses can also provide aerodynamic and structural performance estimates for IAD systems in appropriate flowfields when testing in relevant environments cannot be performed.

An FSI analysis framework was developed that coupled together the Navier-Stokes flow solver FUN3D and the finite element solver LS-DYNA to perform static aeroelastic analyses of a tension cone IAD. Before an FSI framework can be trusted to provide sufficiently accurate aeroelastic solutions, however, it is important that the framework be grounded in relevant experimental data in order to appropriately configure the model parameters. The work described in this paper explains the aforementioned FSI framework and provides the results of a comparison between FSI simulations and experimental data obtained for a sub-scale inflatable tension cone IAD in supersonic flow. Comparisons included the deflected profiles of the IAD, deformation patterns on the tension shell, drag force of the deflected IAD, and the torus pressure requirement to maintain a fully-inflated shape. Examination of the FSI results revealed that the material model did not yield an acceptable simulation of the observed tension cone behavior using material properties derived from mechanical test data. A sensitivity study on the material properties indicated that the model required a significantly lower shear modulus than was obtained from mechanical testing to recover appropriate IAD deflections. Using this lower shear modulus, the FSI results demonstrated very similar static aeroelastic behavior as observed in the test articles, both in their fully inflated state and in their collapsed state (shown below).

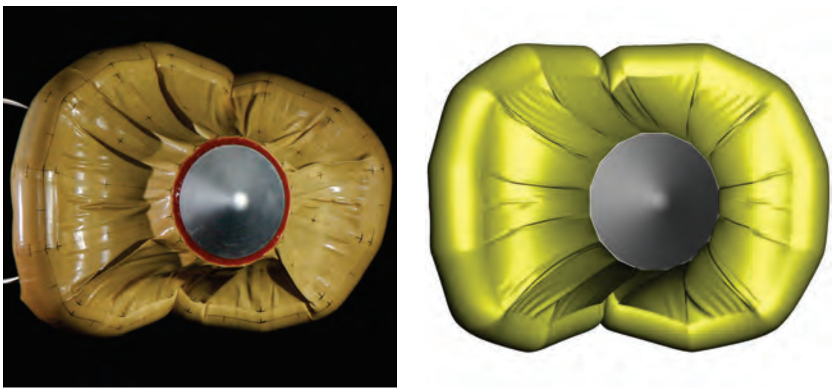

Figure 1. Comparison of test image and FSI result of a fully collapsed tension cone.

VLBI and Doppler tracking of Venus Express spacecraft

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Very Long Baseline Interferometry (VLBI) and Doppler tracking is one of the most powerful tools for determining accurately the position of a planetary spacecraft. The Planetary Radio Interferometry and Doppler Experiment (PRIDE), an initiative by the Joint Institute for VLBI in Europe, is a multi-purpose, multi-disciplinary enhancement of planetary missions science return. PRIDE is able to provide ultra-precise estimates of spacecraft state vectors based on the VLBI phase-reference and radial Doppler measurements.

As a preparatory stage for the future deep space missions, PRIDE has been conducting test observations with several ESA's planetary spacecraft for the last three years (2009-2012). The ESA Venus Express (VEX), launched in 2004, has been the primarily target of our single-dish and VLBI observations. The VEX single-dish observations have been crutial to determine the characteristic of the interplanetary scintillations (IPS) at different solar elongation and at various distances to the target. The analysis of the phase fluctuations on the spacecraft signal allows us to determine the best time frame for the approach, descent and landing operations for spacecraft to achieve precise estimation of the state vectors with VLBI spacecraft tracking.

In this paper, the analysis of the single-dish observations and the interplanetary plasma are presented, as well as the results of the VLBI and Doppler tracking session with the largest amount of radio telescopes so far. This VLBI tracking observation was conducted in 2011.03.28 using 10 different antennas located worldwide. The position of the VEX was estimated with high precision after three hours of intensive observations.

INSTRUMENTATION FOR THE CHARACTERIZATION OF INFLATABLE STRUCTURES

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ABSTRACT

Current entry, descent, and landing technologies are not practical for heavy payloads due to mass and volume constraints dictated by limitations imposed by launch vehicle fairings. Therefore, new technologies are now being explored to provide a mass- and volume-efficient solution for heavy payload capabilities, including Inflatable Aerodynamic Decelerators (IAD) [1]. Consideration of IADs for space applications has prompted the development of instrumentation systems for integration with flexible structures to characterize system response to flight-like environment testing. This development opportunity faces many challenges specific to inflatable structures in extreme environments, including but not limited to physical flexibility, packaging, temperature, structural integration and data acquisition [2].

In the spring of 2012, two large scale Hypersonic Inflatable Aerodynamic Decelerators (HIAD) will be tested in the National Full-Scale Aerodynamics Complex's 40' by 80' wind tunnel at NASA Ames Research Center. The test series will characterize the performance of a 3.0 m and 6.0 m HIAD at various angles of attack and levels of inflation during flight-like loading. To analyze the performance of these inflatable test articles as they undergo aerodynamic loading, many instrumentation systems have been researched and developed. These systems will utilize new experimental sensing systems developed by the HIAD ground test campaign instrumentation team, in addition to traditional wind tunnel sensing techniques in an effort to improve test article characterization and model validation. During the 2012 test series the instrumentation systems will target inflatable aeroshell static and dynamic deformation, structural strap loading, surface pressure distribution, localized skin deflection, and torus inflation pressure.

This paper will offer an overview of inflatable structure instrumentation, and provide detail into the design and implementation of the sensors systems that will be utilized during the 2012 HIAD ground test campaign.

[1] Clark, I.G., Hutchings, A.L., Tanner, C.L., Braun, R.D., "Supersonic Inflatable Aerodynamic Decelerators for Use on Future Robotic Missions to Mars," Journal of Spacecraft and Rockets, Vol. 46, No. 2, March 2009.

[2] Brandon, E.J. et al., Structural Health Management Technologies for Inflatable / Deployable Structures: Integrated Sensing and Self-Healing, Acta Astronautica (2010), doi:10.1016/j.actaastro.2010.08.016

A. Guarneros Luna (Student): A Flight Technology Demonstration of a Space Plug and Play Avionics (SPA) Module for Future Planetary Probes

A Flight Technology Demonstration of a Space Plug and Play Avionics (SPA) Module for Future Planetary Probes

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The primary goal of the Technical Education Satellite (TechEdSat) project is to employ a small spacecraft to evaluate, demonstrate and validate new technologies that are critical to the development future planetary probes and small Earth orbit satellites. In particular, the development of a Space Plug and Play (SPA) software architecture permits relatively easy reconfiguration and inclusion of different sensors in an instrument suite - which may be first be individually tested in a modular manner, and later easily integrated at a higher system level. The instrument suite can be partitioned for use during the re-entry flight phase (e.g., to collect valuable flight data), or after the terminal landing phase when the surface science mission begins. An attractive feature is that the hardware design includes radiation tolerant components - such as the Actel PROASIC-3 Field Programmable Gate Array (FPGA). The SPA architecture is being evaluated for use as the the avionics/power distribution system for the Atromos Mars Surface Science Mission proposed for flight later in the decade. At present, the TechEdSat flight experiment will be jettisoned from the International Space Station (ISS) later in the fall of 2012 and permit the initial evaluation of flight performance. In addition, two Single Burst Data (SBD) modems will be evaluated for use as geographically independent data links for the related Mars probe design re-entry validation experiments in the Earth atmosphere. The results of this work will be to allow relatively inexpensive surface science stations to be developed, as well as a simplified Entry/Descent/Landing (EDL) design that will enable small Mars surface science and other missions.

Fig. 1. A CubeSat Mars Surface lander using SPA architecture and sensor suite.

Session 8: Close-out

B. Johns: Austerity in the age of innovation

Title:
Austerity In the Age of Innovation

Abstract:
Federal budget cuts, deficit spending, raising the debt ceiling, mandatory spending, fiscal responsibility, balancing the budget – these phrases are guiding much of the debate on Capitol Hill and the 2012 election campaigns. This rhetoric affects you and the funding for the sciences.

The Obama Administration believes that funding the sciences and education is the way to, "Out innovate, out educate, and out build," the rest of the world and has proposed a federal budget that supports this initiative. However, the debate in Congress is about how the federal deficit impacts our global economic competitiveness and how cuts in spending are necessary for a stable government. This debate has led to a late enactment of the fiscal year 2011 federal budget and next year's 2013 federal budget is expected to be delayed because of the election.

The current political climate has caused Congress's approval rating to reach an all time low and created confusion on how the federal budget process usually works. There are points throughout the year when you can make an impact on the policy making process. The Decadal Surveys produced by the astrophysics, planetary science and heliophysics communities in the United States, impact policy by the community coming to a consensus and prioritizing the science it wants to accomplish within the decade.

I will speak on the current events on the federal budget, the current climate for science funding, and the impact you can make on the policy making process for science and astronomy.

Poster Presentations

Session 2: Giant Planets

D. Atkinson : Scientific Value of a Saturn Atmospheric Probe Mission

Scientific Value of a Saturn Atmospheric Probe Mission

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Atmospheric entry probe missions to the giant planets can uniquely discriminate between competing theories of solar system formation and the origin and evolution of the giant planets and their atmospheres. This provides for important comparative studies of the gas and ice giants, and to provide a laboratory for studying the atmospheric chemistries, dynamics, and interiors of all the planets including Earth. The giant planets also represent a valuable link to extrasolar planetary systems. As outlined in the recent Planetary Decadal Survey, a Saturn Probe mission - with a shallow probe - ranks as a high priority for a New Frontiers class mission [1].

Atmospheric constituents are needed to constrain theories of solar system formation and the origin and evolution of the giant planets, and can be accessed and sampled by shallow entry probes. Many of these important constituents are spectrally inactive or are beneath an optically thick overburden at useful wavelengths, and therefore are not accessible by remote sensing, such as from Cassini. A small, scientifically focused shallow entry probe mission can make the critical abundance measurements of key constituents, and can measure depth profiles of atmospheric structure and dynamics at a significantly higher vertical resolution than can be achieved by remote sensing techniques alone.
The Galileo mission began the detailed study of the solar system's two major gas giants by dropping an entry probe into the atmosphere of Jupiter and deploying an orbiter around Jupiter. Detailed gravitational and magnetic field measurements of Jupiter, along with a determination of the deep oxygen abundance will be made by the Juno mission in 2016-17. In the same period the Cassini Saturn Orbiter will begin a set of Juno-like orbits to make comparable measurements of Saturn. A Saturn atmospheric entry probe would complete the quartet of missions needed to comprehensively and comparatively study the two planets [2].

Keeping the scientific mission highly focused with a minimal science payload enables an outer planet mission that fits within existing program budget caps while still addressing unique and critical science. Fundamental measurements made from a small and scientifically focused Saturn entry probe include abundances of the noble gases He, Ne, Ar, Kr, and Xe, abundances of key isotopic ratios $^{4}He/^{3}He$, D/H, $^{15}N/^{14}N$, $^{18}O/^{16}O$, and $^{13}C/^{12}C$, and detection of disequilibrium species such as CO, PH_3, AsH_3, and GeH_4. These are diagnostic of deeper internal processes and dynamics of the atmosphere along the probe descent path. Abundances of these key constituents, as well as carbon, which does not condense at Saturn, sulfur, which is expected to be well-mixed below the 4 to 5-bar ammonium hydrosulfide (NH_4SH) cloud, and gradients of nitrogen below the NH_4SH cloud, and oxygen in the upper layers of the water and water-ammonia solution cloud, can be measured by a shallow entry probe descending through 5 or 10 bars.

A shallow Saturn probe is capable of obtaining the key noble gas and isotopic abundances, plus vertical abundance profiles for other constituents not accessible to an orbiter mission. In concert with the results from Galileo, Cassini, and Juno, these measurements are critical to enabling a full comparison of composition and dynamical processes on Jupiter and Saturn. A better understanding of the structure of the gas and ice giants in our solar system will ultimately aid future studies of exoplanets, as well.

References: [1] NRC Space Studies Board Planetary Decadal Survey, Visions and Voyages for Planetary Science in the Decade 2013-2022. [2] NRC Space Studies Board COMPLEX Report, A Strategy for Exploration of the Outer Planets: 1986-1996.

Session 3: Titan

A. Solomonidou (Student) : Cryovolcanic candidate regions on Titan: Promising landing sites

Cryovolcanic candidate regions on Titan: Promising landing sites

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The still on-going Cassini-Huygens mission has significantly advanced our understanding of Titan and its atmospheric and surface complexity since 2004. From the detailed account of the landforms traced in the data of the Cassini instrumentation we are able to distinguish a variety of geological features that resemble those present on Earth. The observed morphotectonic features [1], the cryovolcanic candidate regions [2] and the correlation of the interior-surface-atmosphere system are some of the many issues that demand further extensive exploration by a return mission that will focus on these aspects with enhanced in situ capability and intruments with higher resolution. Several such missions were proposed in the past, like the Titan Saturn System Mission (TSSM) [3], AVIATR [4] and the Titan Mare Explorer (TiME) [5]. One of every mission's goals is to achieve a safe and successful landing on a Titan location. An ideal landing site should combine scientifically interesting aspects, like a variety of geological features and geophysical phenomena that could be investigated and which are simultaneously attached to atmospheric processes. Furthermore, the lander should settle in a 'friendly' environment from a system engineering point of view. In this study we present three candidate cryovolcanic regions on Titan that present multivariable geomorphology, Tui Regio, Hotei Regio and Sotra Facula. These regions seem to be related with internal processes and are also possible 'pathways' for the release of methane in the atmosphere. We present the case as to why these regions would be promising candidate sites for a future landed mission to Titan.

[1] Solomonidou, A., et al., (2011). Planetary Space Science. Submitted.
[2] Solomonidou, A., et al., (2012). In preparation.
[3] TSSM, NASA/ESA Final Report, 30 January 2009.
[4] Barnes, J.W., et al., (2010). 41st LPSC, No. 1533, p.2551.
[5] Stofan, E., et al., (2009). DPS meeting #41, 41.

Titan lake investigation with MEMS

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Titan, Saturn's satellite, is one of the most interesting bodies in the Planetary Geology domain. Since 2004, the Cassini/Huygens mission has been unveiling Titan's complex surface through the use of instruments such as the Visual and Infrared Mapping Spectrometer (VIMS), the Imaging Science Subsystem (ISS), the Synthetic Aperture Radar (SAR) in addition to the Huygens probe measurements and observations by the Descent Imager Spectral Radiometer (DISR), the Surface Science Package (SSP) and the Gas Chromatograph Mass Spectrometer (GCMS). The study and processing of the acquired data suggest that Titan may be geologically active and could support tectonic processes while a number of intriguing surface expressions have been reported. Such features are suggested to be the result of specific geological processes for which internal and/or surface and/or atmospheric dynamics are responsible [1]. In many ways, Titan resembles an organic factory where complex organic chemistry occurs on the upper atmosphere when EUV photons interact with nitrogen and methane to form complex organic molecules. The heavier photochemical products aggregate lower in the atmosphere forming the thick hazy layers. The alcanological cycle closes in the troposphere where hydrocarbon products fall onto the surface, in where the hydrocarbons can exist as a liquid to shape lakes and dendritic networks or as ice to form pebbles and equatorial dunes [2]. Indeed, Titan is the only planetary body, other than Earth that hosts numerous lakes, mainly concentrated in the northern polar region [3]. During the Cassini/Huygens mission, the lakes have shown variations through time. For instance, the shoreline of the Ontario Lake retreated within 2004 and 2009 due to evaporation and infiltration [4]. Furthermore, other than the atmospheric contribution of material into the lakes, the rounded shorelines of a number of lakes and the absence of tributaries indicate that subsurface exchanges may occur through infiltration [3], since Titan's upper crust is considered as likely porous [5]. Hence, the connections among the lakes, the atmosphere and the interior as well as the lakes' astrobiological potential are in the forefront of investigation and modeling. The identification of the exact composition of the lakes between the two hemispheres will give us information on their refurbishment, providing clues also for the internal structure of Titan. On the other hand, the surface liquids are also of astrobiological interest. In the case of a future mission landing in a lake (like the proposed TSSM lake lander [6], the Titan lake probe [7] and TiME [8]), MEMS micro probes as part of the payload could help us probe the composition and the physical parameters of the liquid and its surroundings. MEMS devices seem ideal for such an experiment since they are low budget instrumentation with significantly reduced size. MEMS sensors will help reconstruct the temperature and the pressure vertical profile within the liquid deposit, while they will operate at the same time as internal sources of radiation giving the opportunity to the lake lander to analyze the composition and the structure of the lake [6;9].

[1] Solomonidou, A. et al. 2012. Planetary and Space Science. Submitted.
[2] Lorenz, R.D. et al. 2008. Geophysical Research Letters, 35, L02206.
[3] Hayes, A.G. et al. 2008. Geophysical Research Letters, 35, L09204.
[4] Turtle, E.P. et al. 2011. Icarus, 212, 2, 957-959.
[5] Mitchell, J. 2008 Journal of Geophysical Research, 113, E08015.
[6] TSSM, NASA/ESA Final Report, 30 January 2009.
[7] Waite H.J. et al. 2010. Planetary Science Decadal Survey-JPL.
[8] Stofan E. et al. 2011. EPSC-DPS Assembly, Nantes 3-8 Oct, p.909.
[9] Bampasidis G. et al. 2011. Proc. of 2nd ICST, Athens, Greece, doi:10.1109/ICSpT.2011.6064648.

Simulation of Titan atmosphere by an arc-heated facility

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The Small Planetary Entry Simulator (SPES) of DIAS in Naples is in operation from long time. Main SPES components are:

1) Electric arc-heater (industrial plasma torch, Sulzer-Metco type 9-M), operating with pure inert gases (argon or nitrogen);

2) A mixing chamber where the nitrogen plasma can be mixed with cold gases (oxygen, carbon dioxide) to simulate planetary atmospheres;

3) Four conical nozzles (area ratios 4, 20, 56, 100) for operation in supersonic/hypersonic flow regime;

4) A cylindrical vacuum test chamber. Ultimate pressure in the test chamber is 50 [Pa].

Typical SPES operation for entry simulation applications involves the following values (order of magnitude):

- Total mass flow : 1 (g/s) - average total enthalpy : 15 (MJ/kg) - total pressure : 0. 5 x 10^5 (Pa)

Up to now SPES has been used to simulate entry conditions for Earth and Mars atmospheres; recently we envisaged the opportunity to upgrade SPES for entry applications in the Titan atmosphere, which involves the use of methane as cold gas to be mixed with the nitrogen plasma.

A preliminary analysis of a typical entry trajectory in the Titan atmosphere allow us to estimate the values of simulation parameters to be reproduced in SPES. The results of this analysis are shown in the paper. Special issues related to the use of methane in SPES are described in the paper also, with the new operation map and related flow properties such stagnation pressure, stagnation-point heat flux and others.

MEMS-based seismic sensors on Titan and Enceladus

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The history of seismometers as payloads for space missions dates back to Ranger 3 in early 1962, which was launched to study the Moon. Active and passive seismic experiments were successfully performed on the Moon as well as on Mars and Venus [1]. The Cassini/Huygens mission, still on-going on the Saturnian system, send us back a wealth of data about Titan, the biggest satellite of Saturn, and Enceladus, its active intriguing moon. Remote sensing data from Cassini indicate that Titan's interior is partially differentiated. Indeed, the variations of its degree 2 coefficient gravitational potential provided by the Cassini Radio Science Subsystem (RSS) support internal density variations [2]. Additionally, the Cassini Synthetic Aperture Radar data suggest non-sychronous spin rate [3], and the Permittivity, Waves and Altimetry (PWA) sensor on the Huygens Atmosphere Structure Instrument (HASI) with the Cassini Radio and Plasma Wave Science (RPWS) recorded Schumann resonance [4], giving evidence for internal ocean. Hence, the possible Titan's internal structure from the interior to the surface is as follows: (a) a silicate core, (b) a high-pressure water ice layer, (c) an ammonia-rich ocean and (d) an ice I layer covered by a crust of organics and ices [5]. Furthermore, the combined Cassini observations of Enceladus by the Cassini Plasma Spectrometer (CAPS), the Ion and Neutral Mass Spectrometer (INMS) and the Ultraviolet Imaging Spectrograph (UVIS) instruments detected water vapor geysers at the south polar region [6]. These observations in addition to the Imaging Science Subsystem (ISS) instrument ones that showed internal material jetting from fractures in the surface implied that a thin ice lithosphere exists over a liquid reservoir [7]. The internal stratigraphy is based on thermal evolution models since reliable data to contstrain the differentiation of Enceladus are missing [8]. Thus, Enceladus' internal differentiated structure from the interior to the surface is as follows: (a) a large rock-metal core, (b) a water ice shell possibly melted (liquid) at depth [8]. Seismic experiments can detect the presence of these internal layers of the Saturnian moons. Seismic waves, when they pass from the fringes of layers with different densities or changes in temperature, refract, since the local seismic velocities are different. These boundaries are identifiers of changes in rock types of the interior. The waves can be detected through a network of sensors and help us modelling the internal structure. We propose a seismic network to be part of the geophysical payload of such forthcoming missions [9]. A seismic network can be consisted of an array of sensors based on the promising technology of Micro-Electromechanic Systems (MEMS) as well as several piezoelectric transducers [10], and new developments based on laser-interferometric sensing or convection in electrolytic liquids. This network, which resembles a geophone array widely used on the Earth, can detect ground motions caused by natural sources (passive experiment) or controlled (active experiment).

[1] Knapmeyer M. et al. 2012. EGU2012-5031, GI2.3/PS1.3; [2] Rappaport N.J. et al. 2008. Icarus, 194, 711–720; [3] Lorenz R.D. et al. 2008. Science, 319, 1649–1651; [4] Beghin C. et al. 2009. PSS, 57, 1872–1888; [5] Tobie G. et al. 2005. Icarus, 175, 496–502; [6] Matson et al. 2007. Icarus, 187, 569-573.
[7] Collins G. & Goodman J. 2007. Icarus, 189, 72–82; [8] Tobie G. et al. 2008. Icarus, 196, 642–652.
[9] Lorenz R. et al. 2009. Solar System Decadal Survey 2013-2023; [10] Bampasidis G. et al. 2011. Proc. of 2nd ICST, Athens, Greece, DOI: 10.1109/ICSpT.2011.6064648.

Session 4: Venus

E. Stern (Student) : CFD Simulations of the Dynamic Stability of Deployable Aeroshells for Venus Entry

CFD Simulations of the Dynamic Stability of Deployable Aeroshells for Venus Entry

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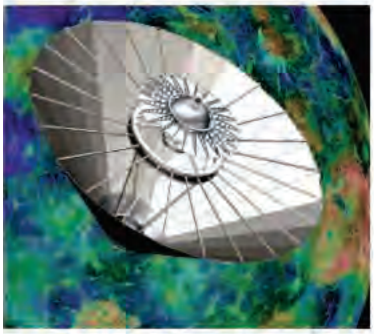
Abstract:

A mechanically deployable entry system concept, known as the Adaptive Deployable Entry ProjecT (ADEPT) [1], is currently being considered for development at NASA for future robotic missions to Venus and Saturn, as well as for delivering high-mass payloads to Mars. The mechanically deployable



aeroshell concept proposes to have a flexible thermal protection system (TPS) that wll be folded and stowed during launch. Then, prior to the entry, descent, and landing (EDL) phase of the mission, the TPS will be deployed using a system of ribs and struts, as illustrated in the figure on the left. By removing the constraint that the launch vehicle fairing places on the maximum diameter of the aeroshell, the entry vehichle may access lower ballistic coefficient trajectories. These allow for entry conditions which are typically more benign (i.e. lower heating and deceleration loads) than those for the high ballistic coefficient rigid aeroshells. Reducing the extreme loads reduces the amount of TPS and structural robustness required for the vehicle, and therefore enables more payload mass.

This work shall focus on trying to understand the aerodynamic performance of such a vehicle. In particular we will focus on assessing the *dynamic* stability of a representative geometry for the transonic portion of a notional Venus entry trajectory. Legacy sphere-cone aeroshells (i.e. Viking-like shapes, etc.) have been known to encounter undamped dynamic oscillations in the low-supersonic to transonic regime, and thus it is critically importatnt to understand this for these new deployable concepts as well.

The dynamic response of the vehicle during this regime is highly coupled to the fluid dynamics of the wake, thus requiring high accuracy modeling of the relevant wake physics[2]. To accomplish this, the approach used for this work will involve using a high fidelity computational fluid dyamics (CFD) code to do dynamic simuations of a simplified representation of the vehicle geometry. We will leverage novel grid deformation techniques[3], developed for doing fluid structure interaction (FSI) simulations, to allow the vehicle to freely rotate within the computational domain. Analysis of the resulting trajectories will yield aerodynamic derivatives, giving insight into the relative dynamic performance of these vehicles. Additionally, we will examine the effect that using higher order numerical schemes has on the computed coefficients, in order to provide insight for future simulation work in this area.

References:

[1] E. Venkatapathy, J. Arnold, I. Fernandez, K. Hamm, D. Kinney, B. Laub, M. K. McGuire, K. Peterson, D. Prabhu, D. Empey, I. Dupzyk, L. Huynh, P. Hajela, P. Gage, A. Howard, and D. Andrews, "Adaptive deployable entry and placement technology (ADEPT): A feasibility study for human mission to mars," in *21st AIAA Aerodynamic Decelerators Systems Technology Conference*, no. 2011-2608, Dublin, June 2010.

[2] E. Stern, M. Barnhardt, E. Venkatapathy, G. Candler, and D. Prabhu, "Investigation of Transonic Wake Dynamics for Mechanically Deployable Entry Systems", *IEEE Aerospace Conference*, Big Sky, 2012

[3] V. Gidzak and G. V. Candler, "Validation of Fluid-Structure Interaction Capabilities in US3D," *AIAA Paper*, No. 2011-2543, 2011.

Session 5: Mars

P. Withers : Empirical predictions of martian surface pressure in support of the landing of Mars Science Laboratory

EMPIRICAL PREDICTIONS OF MARTIAN SURFACE PRESSURE IN SUPPORT OF THE LANDING OF MARS SCIENCE LABORATORY

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ABSTRACT

Landing a spacecraft on Mars is tough. Unlike the Moon, Mars has enough atmosphere to require extensive thermal protection systems, such as heatshields. Unlike Venus and Titan, Mars has too tenuous an atmosphere for low-Mach parachutes alone to provide enough deceleration for a safe landing. Hence complicated landing systems, such as that used by Mars Science Laboratory, are required. A critical input to the design of Mars EDL systems is the surface pressure, which is essentially the mass of the atmospheric column. Here we explore ways to predict the surface pressure for the EDL of Mars Science Laboratory.

1. INTRODUCTION

The aim of this work is to develop an empirical expression for diurnal mean martian surface pressure in support of the landing of Mars Science Laboratory. We evaluate the consistency of surface pressure measurements from four landers, Viking Lander 1, Viking Lander 2, Mars Pathfinder, and Phoenix, and one radio occultation experiment, Mars Global Surveyor. With the exception of Mars Pathfinder, whose measurements are 0.1 mbar smaller than expected, all are consistent. We assume that the diurnal mean surface pressure is a separable function of altitude and season, neglecting dependences on time of day, latitude, and longitude, and use the Viking Lander 1 dataset to characterize the seasonal dependence as a harmonic function of season with annual and semi-annual periods. We characterize the exponential dependence of surface pressure on altitude using Mars Global Surveyor radio occultation measurements widely-distributed below +1 km altitude and within 45 degrees of the equator. Our empirical expression for diurnal surface pressure, p_{dm}, is $p_{0,VL1} \exp\left(-\left(z - z_{0,VL1}\right)/H_0\right)$ $\left(1 + s_{1,VL1}\sin\left(1L_s\right) + c_{1,VL1}\cos\left(1L_s\right) + s_{2,VL1}\sin\left(2L_s\right) + c_{2,VL1}\cos\left(2L_s\right)\right)$ where z is altitude, L_s is season, the reference pressure, $p_{0,VL1}$, is 7.972 mbar, the altitude of Viking Lander 1, $z_{0,VL1}$, is -3.63 km, the reference scale height, H_0, is 11 km, and the harmonic coefficients are s_1 = -0.069, c_1 = 0.060, s_2 = 0.045, and c_2 = -0.050. We validate this expression against the available datasets and predict, with a 1-σ confidence level of 2%, a diurnal mean surface pressure of 7.30 mbar at Gale Crater, the Mars Science Laboratory landing site, at $L_s = 150°$.

2. OTHER APPLICATIONS

The operational implications of simple and accurate methods for predicting martian surface pressure extend beyond MSL. From an operational perspective, other mission design efforts can use the work reported here to make first-order estimates of surface pressure for candidate landing sites and times. They can also use it as a straight-forward "reality-check" on the predictions of more complex models.

There are also potential scientific applications, such as the determination of the total atmospheric mass. Variations in the total mass of the martian atmosphere with time are important for several research areas, including the martian rotational state and the martian gravitational field. The atmospheric mass per unit area is the surface pressure divided by the acceleration of gravity. Using our empirical expression for diurnal surface pressure, we find that the predicted mean total atmospheric mass is approximately 2.4×10^{16} kg. The predicted difference between the maximum and minimum atmospheric mass is 6.6×10^{15} kg, or 27% of the mean atmospheric mass. If this mass difference were uniformally deposited in one hemisphere at latitudes poleward of 75° (or 65°) with a density of 910 kg m^{-3}, then the resultant seasonal polar cap would have a height of 3 m (or 1 m). These estimates of total atmospheric mass, range in atmospheric mass, and seasonal elevation changes are broadly consistent with earlier publications which builds confidence in our empirical expression.

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The simulation of one side of tetrahedron airbags impact attenuation system

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Abstract

The characteristic of a lander with tetrahedral airbags which would be used for impact attenuation device in Mars exploration was investigated in this paper. Attenuation process of one of four sides of airbags impacting onto the earth has been simulated. Parametric studies can be performed, and modification to the airbags system design can be investigated by changing different parameters. Optimization of parameters can be obtained for design.

According to the modeling study and assuming that the aerodynamic drag force and volume change of non-impact sides of airbags are neglected, and inner gas is assuming to be ideal gas, equations of the attenuation process were founded and coded. By the simulation, some valuable results were got, such as the change of the internal pressure and the impact deceleration, which were validity with the delivery test. The both coincide with each other, as shown in Figure 1. By analysis, this paper got the effects of the diameter of gas internal orifice of airbags and initial differential pressure on the attenuation characteristic.

The value of this paper is the optimal diameter of gas orifices which can minimize the peak overload and rebound velocity in the attenuation process, as shown in Figure 2, and more efficient for design of landing attenuation airbag.

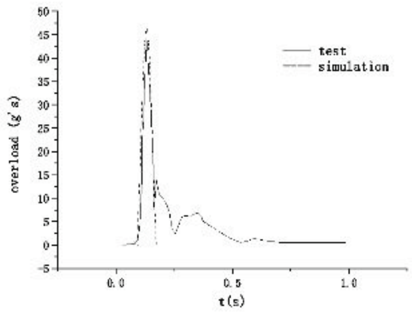

Figure.1 time domain curve of the simulation and test

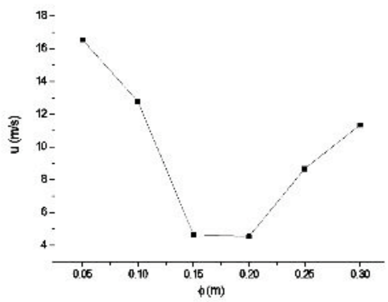

Figure.2 rebound velocities at different gas orifices

Integrated Trajectory, Atmosphere, and Aerothermal Reconstruction Methodology Using the MEDLI Dataset

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The 2012 Mars Science Laboratory (MSL) mission will include instrumentation on its aeroshell that will collect pressure distribution across the forebody, take in-depth temperature profiles of the Thermal Protection System (TPS), and provide an isotherm depth measurement at different locations on the heatshield. The sensors are part of the MSL Entry, Descent, and Landing Instrumentation (MEDLI) package and are divided into two separate sensor suites: Mars Entry Atmospheric Data System (MEADS) that collects the pressure measurements and the MEDLI Integrated Sensor Plug (MISP) that provides the temeperature and isotherm measurements.

Almost all past reconstruction efforts have looked into doing the trajectory and atmospheric reconstruction separately from the aerothermodynamics and TPS material response parameter estimation. However, an integrated approach to the reconstruction of the MEDLI data has the possibility to improve upon the two, independent analyses of the atmospheric and aerothermodynamic data types due to the correlated nature of the EDL design. For example, the TPS performance is driven by the aeroheating environment, which itself is a function of the vehicle's trajectory. Additionally, TPS material response can affect the shape of vehicle and its aerodynamics, thus changing the vehicle trajectory. Thus, processing trajectory and atmospheric measurements might improve the estimation of aerothermodynamic and TPS response parameters and vice versa.

The authors have demonstrated successful results in conducting the two types of reconstruction independently, and this paper proposes the assimilation of the two estimation methodologies for a thorough processing of the entire MEDLI dataset. This research proposes two possible integrated reconstruction methodologies:

a) Sequential approach: MEADS data reconstruction occurs first resulting in an estimated trajectory, atmospheric profile parameters and aerodynamic coefficients. A new nominal aeroheating environment is generated from the estimated trajectory using CFD tools and then this is used as an initial condition in the aeroheating estimation process using MISP data.
b) Simultaneous approach: This approach will capitalize on the coupling between the two types of MEDLI measurements and conduct the estimation process of trajectory and aerothermodynamic properties in tandem. The reconstruction process will happen in one estimator with an augmented state vector that encompasses trajectory, atmospheric, aerodynamic, aeroheating and TPS response parameters. The internal coupling between the two processes could be simplified with engineering models such as the NASA-developed Configuration Based Aerodynamics (CBAERO) software anchored with CFD simulations.

The paper proposes a comprehensive way of conducting both proceses of estimation in detail and will identify the advantages and possible pitfalls in the methodology.

High Level Shock Tests for Mars MetNet Penetrator Payload

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Within the next 8 years a Finnish-Russian-Spanish team will deploy a network of meteorological observation stations on the surface of Mars. This Mars MetNet mission is formed by a set of small approximately 20 kg landing units, deployed from several Mars orbiting satellites. MetNet Landers are not using any parachutes during decent phase, but they only utilize inflatable aerobreaking devices. The MetNet landers are semi-hard penetrators and the impact speed to Martian surface is high, all included sub-systems have to survive the impact shock of the landing.

In qualifying the Mars MetNet Landers instruments; MetBaro, atmospheric pressure sensor, and MetHumi, atmospheric humidity (MetHumi) sensor, high impact shock tests up to 500g were conducted. For the testing a pressurized air cannon designed for special aircraft testing at the INTA (Institutio Nacional de Técnica Aerospacial) facility close to Madrid was used. The cannon works with compressed air and is normally used to test the resistance of different airplane parts to the impact of birds.

The required shock of 500g for 15 to 20 ms was achieved by attaching a metallic plate "target" to the end of the barrel of the cannon. The instruments were encapsulated by a polystyrene bullet that was fired with the cannon. The g-forces were measured by using a special accelerometer designed by INTA. The battery powered accelerometers measured the acceleration profile and stored it to internal memory that was downloaded to computers after the impact for analysis. The shock, which the instrument experienced, was measured along all three main axes (x, y and z).

Instrument accommodation: For each test axis a separate bullet made of expanded polystyrene was formed and two holes carved into it, into which the respective instruments were fitted tightly in the orientation required for the planned test. The instruments were placed into small plastic bags to prevent contamination by the polystyrene dust formed by the impact of the bullet to the target.

Before each shock test, both instruments were tested in the laboratory to ensure that they were fully functional. These results were used as reference for the functional test following each of the 500g shock tests. The actual shock test was performed in three phases; 1) MetHumi instrument was tested in the X-axis direction and the MetBaro instrument in the Y-axis direction, 2) MetHumi was shocked in the Z-axis direction and MetBaro in the X-axis direction, and 3) the MetHumi was shocked in the Y-axis direction and MetBaro in the Z-axis direction.

Both instruments survived all three 500g shock test firings. The recorded shock spectra of all three shock tests were according to the requirements specified for the instruments onboard Mars MetNet Mission.

Mars subsurface analysis: a drilling system coupled with a miniaturized spectrometer

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The observation and analysis of Mars soil in the shallow subsurface is the main goal of the future rover explorations. The investigation of subsurface unaltered by weathering process, oxidation and erosion, will provide a direct indication of the geological evolution of the soil material. With this purpose, one of the ExoMars mission is dedicated to the exploration of Mars soil with a rover equipped with a Drill to perform in situ investigations down to 2 meter in the Mars soil. Ma_Miss (Mars Multispectral Imager for Subsurface Studies) is a spectrometer devoted to observe the lateral wall of the borehole generated by the Drilling system. The instrument is fully integrated with the Drill and shares its structure and electronics. Ma_Miss is a miniaturized near-infrared imaging spectrometer in the range 0.4-2.2 μm with 20nm spectral sampling. Miniaturization is the key factor to permit the embedding of Ma_Miss in the Drill, in particular for those elements in Drill tool whose internal diameter is only 21 mm. A transparent sapphire window on Drill Tip protects the Ma_Miss Optical Head permitting the observation of the borehole wall. Hardness of sapphire is the closest to diamond one, thus avoiding the risk of scratches on its surface. Ma_Miss Optical Head performs the double task of illuminating the borehole wall with a spot around 1 mm diameter and of collecting the scattered light coming from a 0.1 mm diameter spot of the target. The signal is transmitted from the optical relay in the Drill tip to the spectrometer in the Drill box by means of various optical fibers installed in the different elements of the Drill tool and of an optical rotary joint implemented in the roto-translation group of the Drill. . The spectrometer, including proximity electronics, is located on the Drill Box where the signal is transmitted through the fiber optics. Ma_Miss provides high flexibility in the acquisition of borehole wall spectra by means of the translational and rotational agility of the Drill tool. The spectrometer observes a single point target of the borehole wall surface. Depending on the observation strategy, the drill tip could perform a vertical translation or a 360 degrees rotation. In the first case, the spectrometer will acquire a "Column Image"; in the second case a "Ring Image" will be carried out. The acquisition of adjacent rings will permit to reconstruct a complete image of the borehole wall. Given the high flexibility in the Ma_Miss operations, a large variety of acquisition strategies can be implemented, depending on the specific target. The Ma_Miss tip breadboard has been developed and tested. The tip breadboard has been coupled to a laboratory spectrometer for the analysis of the signal transmitted. Different reflectance spectra of several mineral targets were carried out during the test. The Optical Head of Ma_Miss has been tested after integration in ExoMars Drill. The drilling experiment has been carried out in realistic media (tuff, red brick). The test shows good performance of Optical Head illumination capability and of the window cleanliness during the drilling. During the ExoMars Rover mission, the Ma_Miss experiment will allow collecting valuable data of the drilled stratigraphic column, it will document "in-situ" the nature of the samples and it will be able to identify hydrated minerals, sedimentary materials and different kind of diagnostic materials of Martian subsurface. For the first time in Mars exploration, the water and geochemical environment will be investigated as function of depth in the shallow subsurface.

Wind Noise Analysis for a Very Broad Band Seismometer for Mars 2016

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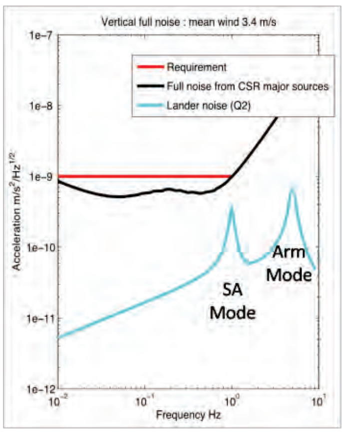
The InSight mission is a candidate to NASA Discovery program and especially includes a Very Broad Band (VBB) Seismometer, with SEIS (Seismic Experiment for Interior Structure). In order to investigate seismic activities with respect to the science objectives, this instrument should be able to take measurements of ground accelerations with an accuracy down to 10^{-9} $m.s^{-2}.Hz^{-1/2}$ (see performance and requirement on figure 1). The (broad) band used for science varies from 10^{-3} Hz to 10 Hz and any noise that will contribute to the error budget on this frequency space is investigated.

The poster will present analysis for noise caused by wind envrionnement on the martian surface given the setting of the mission during science operations (see figure 2). The seismometer is protected using a wind shield that is set around. Both pieces are dropped from the deck to the a near ground location using a robotic arm. The wind environement induces stresses through all the existant hardware. After summing up present knowledge about the martian boundary layer [1], a wind model is chosen that will fit a nominal worst case for the wind velocity spectra used for simulations. This is compared to existing wind data from Viking Lander and large eddies simulations [2].

About four different noises due to wind are identified and their influence on the seismometer is estimated. In some cases the noise could be too high or contribute significantly to the error budget, so that studies include mission design recommandations to minimize noises due to wind. Identified contributions are due to: Wind shield set around the seismometer under drag and lift stresses, Lander under drag and lift stresses, solar panels flapping modes exited by local turbulence length effects and wind drag on the tether used to link the seismometer on the ground with the electronics located on the lander deck.



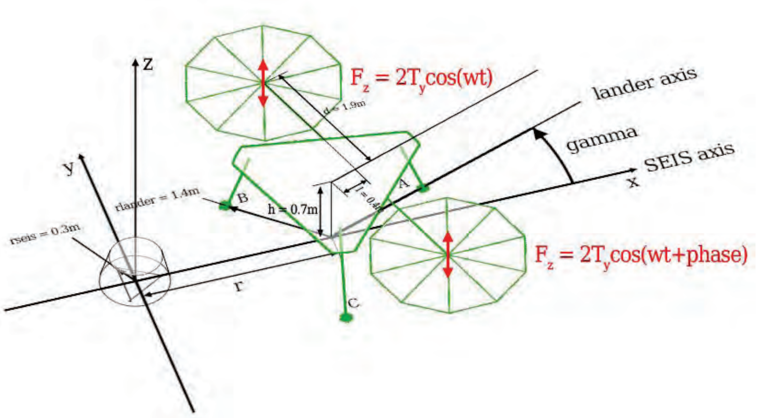


Figure 1 (left), acceleration noise on the VBB due to wind on lander, and Figure 2 (right), setting during science operations.

[1] THE MARTIAN ATMOSPHERIC BOUNDARY LAYER, A. Petrosyan, B. Galperin, S. E. Larsen, S. R. Lewis, A. Määttänen, P. L. Read, N. Renno, L. P. H. T. Rogberg, H. Savijärvi, T. Siili, A. Spiga, A. Toigo, and L. Vázquez (2011), American Geophysical Union. Reviews of Geophysics, 49, RG3005

[2] Structure and Dynamics of the Convective Boundary Layer on Mars as Inferred from Large-Eddy Simulations and Remote-Sensing Measurements, Spiga, A., F. Forget, S.R. Lewis, and D.P. Hinson (2010), Quarterly Journal Royal Meteorological Society, 136, 414-428.

IPPW-9 SEIS : The Mars seismic experiment of the InSight Mission

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The InSight Mission is one of the three proposal selected for the second selection step in the frame of the 2010 Discovery AO. Its goals is to explore the interior structure of Mars.

The SEIS seismometer is the core payload of this mission. It will provide measurement of the ground motion over a very wide bandwidth, from 0.01Hz to 50Hz with an extremely high sensitivity and low noise (below 10^{-9} $m.s^{-2}/Hz^{½}$). Those very stringent requirements have been derived from top level science objectifs to be able to provide unique information on deep Mars structure even in case of a low seismicity of the planet.

Three short period seismic sensors provides high frequency measurement, while three very broad band provides the low frequency ones. The first are based on MEMS technology. The latests are leaf spring inverted pendulum with a displacement transducer and a force feedback. All this sensor head is deployed on thr ground by a robotic arm. An installation system couples the sensors with the ground and level the very broad band. A 24 bits low noise acquisition electronics remains in the lander and control the experiment. Whereas Earth seismometer are installed in vault to provide the best quality data, SEIS design include a thermal shield and a wind shield to be deployed over the seismoter.

A full performances budgets will be presented and will include instrument self noise as well as environmental sensitivity.

If InSight is seleted, this instrument will provide seismic measurement on Mars during one Martian year from the end of 2016 to 2018.

Combined Sensor Assembly COMARS for Martian Atmospheric Entry

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Although the total aerothermal loads on the base of a capsule are significantly lower compared to the front surface loads during Martian entry, special attention has to be paid to the determination of the radiative heating on the base. There is a big lack in prediction of the radiative heating with CFD tools. The ground testing facilities are not able to simulate the entry conditions completely. These facts force system engineers to perform the design with appropriate margins, i.e. higher thickness (mass) of the back cover TPS. Therefore in flight measurements of the aerothermal loads are essential. To close this gap DLR initiated in cooperation with ESA the development of the COMARS+ payload.

The COMARS sensor has been developed to have combined measurements of pressure, temperature, heat flux rate and radiation during Martian entry at different locations on the back shield of the EXOMARS EDM demonstrator. To mount the sensors to the heat shield structure an interface has been designed which is shown in Figure 1. This interface also contains two fibre based IR detectors of CNES (called ICOTOM) [1], which should measure the radiative flux on the back shield during the atmospheric entry and descent of the EXOMARS capsule at two different spectral bands using two different filters. In addition to three COMARS sensors one additional DLR radiometer based on classical design will be integrated close to one of the COMARS sensors. This radiometer will measure the radiative heat flux on the back shield of the EXOMARS EDM demonstrator. The measurement is conducted by a thermopile sensor in a standard transistor outline package. The sensor housing is equipped with a window, so that only the radiative part of the incoming heat flux is measured. The window also acts as a filter for a dedicated wavelength interval

The ICOTOM sensor consists of a small metallic interface to which the optic fibre (including filter) and the IR detector are glued. This interface has a thread for the fixation to the COMARS interface.
The optical access to the back shield surface is provided by the optical fibres which are glued into small boreholes. The pressure measurement is performed by a Pirani-type pressure sensor which is fixed with glue to the COMARS interface. The heat flux measurement (convective+radiative) is performed with a commercial heat flux microsensor. This sensor is clamped in a borehole by the ICOTOM sensors using a small bushing. The sensors and the connector are covered by an Aluminium housing for shielding purposes, see Figure 1. The whole assembly is fixed to the back cover structure using a honeycomb insert provided by TAS-F.

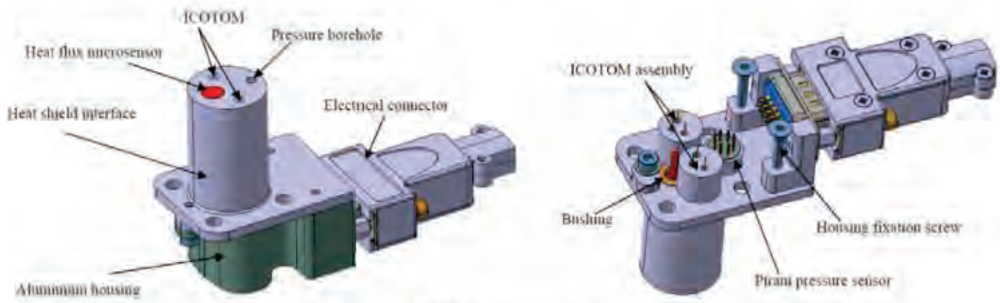

Figure 1: COMARS sensor layout

1. Pierre Omaly, Phillipe Herbert, Ali Gülhan: ICOTOM: Infared Radiometer, IPPW-9, 2012, Toulouse, France.

Results of experimental study in TsAGI IT-2 Hot Shot wind tunnel

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The objective of this work is a description of the test campaign carried out in hot shot wind tunnel IT-2 of TsAGI within the frameworks of WP5 (Task 5.3) of the SACOMAR project [1]. This work covered the following phases:

- Design and manufacturing of a test model with instrumentation;
- Characterization of flow field using total pressure and heat flux gages;
- Measurements of the heat flux rate and pressure on the model surface at defined flow conditions in CO_2 environment in IT-2 facility.

The main objectives of the SACOMAR study are the improvement of experimental and numerical tools to study the aerothermodynamic problems of Martian entry, the achievement of a better understanding of physical phenomena and the creation of a data base.

Analysis of the obtained experimental data (including the data gained from all other facilities involved in the project) allows further improvement of thermochemical model of the Martian atmosphere, that will be used for numerical modeling of Mars atmosphere entry conditions for future vehicles. As a reference trajectory the ExoMars vehicle steep trajectory entry conditions is used in the project (this mission is scheduled by ESA in 2016). A number of upper trajectory points were assigned as reference free stream conditions for on-ground experimental simulation.

The main goal of the investigation in hot shot wind tunnel IT-2 is the modeling of the flow over the agreed model of the cylinder at moderate values of free-stream enthalpy that correspond to the low trajectory of Martian entry (trajectory points FC-4, FC-3 [2]). Previously, wind tunnel IT-2 operated at a standard regime, which approximately corresponding to point FC-4, $H_t \approx 2$ MJ/kg, regime 1 in the Table 1. Carbon dioxide is not dissociated in such a regime, with only the vibrational degrees of freedom of the molecules being excited. That is why it became necessary to increase the total enthalpy of the flow to reach enthalpy $H_t \approx 5.5$ MJ/kg, at which carbon dioxide begins to dissociate partially. This has been attempted. The attempt turned out to be partially successful. enthalpy $H_t \approx 4.6$ MJ/kg ($T_t \approx 3100$ K) was reached, at which approximately 12% of carbon dioxide were dissociated (regime 3). An intermediate regime ($H_t \approx 2.7$ MJ/kg), at which the dissociation only starts, was achieved during this work, regime 2 (Table 1).

Table 1

Test regime	P_t, bar	T_t K	H_t, MJ/kg
1	400	1940	2.24
2	320	2230	2.67
3	250	3100	4.58

According to Test Plan [2], a flat-faced cylinder with a diameter R=50 mm is foreseen for measurements in HEG and IT-2. The edge radius should be identical to the smaller cylinder, i.e. r_e =11.5 mm, Fig. 1.

IPPW-9 Mars Sample Return – Sample Container

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The **Sample Container** has been developed in the frame of ESA contract N° 20230/06/NL/EK and the objective of this activity was to design the Sample Container for the Mars Sample Return mission, manufacture a Structural and Thermal breadboard and a functional breadboard to validate the conception through performance and environmental tests.

The sample container is a very complex component of the Mars Sample Return mission due to the need to comply with the science requirements. In the reference mission for this activity, the sample container is required to remain in Mars orbit for a significant time as a self-standing element waiting for the capture from the Orbiter. This implies functions like electrical power and thermal control to be implemented.

The Sample container consists of the following elements:

- ✓ a main body containing the sample vessels and all the equipment needed to achieve the sample container functions;
- ✓ a lid;
- ✓ two mechanisms to close / open and to lock / unlock the lid;
- ✓ external mechanical and electrical interfaces;
- ✓ retro-reflectors mounted on the outside surface of the container;
- ✓ two RF antennas embedded into the external surface of the container;
- ✓ a battery to provide the required power during the orbital phase.

From the Sample Container definition, some critical items have been identified. A Structural and Thermal Breadboard (STBB) has been defined, manufactured and assembled such that it is representative for the elements to be tested.

The design of the SCSTBB is very close to the nominal definition of the SC.

The structure is flight like expect the coating (alodine instead of gold) and PEEK-HPV instead of VESPEL. The Radom uses Permaglass instead of Ultem. Retroreflectors, batteries, RF beacon and Sample vessels are structural mockup in Aluminum.

MECANO ID proposes to present the SCSTBB in the frame of the 9th International Planetary Probe Worshop.

Together with its EGSE, the Breadboard can be operated to open/close and lock/unlock the lid.

IPPW-9

Mars Aerocapture Technique: Aerothermodynamic Issues

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An important step for human exploration into the solar system is to develop advanced transportation technologies to move humans and cargos between geostationary and low Earth orbits, and also return them from the Moon or from Mars. Such vehicle must rely on aerocapture to be cost effective: using atmospheric drag to slow down space vehicles, within a single aerodynamically controlled entry pass, is regarded as one of the major contributors to make both lunar-return and Martian missions affordable. This technology can result in a large amount of mass saving (up to 30-50% at launch) with regard to more conventional techniques of insertion into an atmosphere using the classical propelled braking. It is also well adapted for heavy weight missions such as sample return and future manned missions.

From the knowledge gained over the last past years either in Europe or in the USA, it is obvious that while the guidance aspects are today mastered, the success of such a complex mission strongly relies on the accurate evaluation of the critical heat loads that the spacecraft will experience during the aerocapture maneuver to ensure efficient thermal protection. Moreover, the vehicle involved is rarely a capsule embedded but rather an orbiter/satellite protected by a shield into an open bay. In the frame of the NASA/CNES program MARS PREMIER (1999-2003), aerothermodynamic analysis has been performed on a Mars Sample Return Orbiter (MSRO) during the aerocapture phase. The vehicle consisted of a raked-and-blunted-elliptical cone based from the previous concept defined by NASA during the AEROASSISTED FLIGHT EXPERIMENT (AFE) program. Experimental wind tunnel campaigns were performed jointly with numerical simulations in order to evaluate heat loads on both the heat shield and the payload, and resulted in significant convective heating on the cylindrical payload (initial design) due to wake closure and impingement of the shear layer. Consequenlty, the phase A configuration were renewed and a partial back-cover were added to protect a more representative design of the payload from convective heating. However, the project were aborted in 2003 following the demonstration of critical radiative heating on the satellite in the open bay. Radiative heat transfer was computed on a simplified axisymmetrical MSRO geometry considering CO_2 infrared emission and the results indicated that the radiative contribution on the payload could reach up to 10% of the stagnation convective heat flux for the exit point of the aerocapture trajectory.

In 2009, EU initiated the AEROFAST collaborative program, led by EADS ASTRIUM Space Transportation, whose goal was the improve the knowledge of planetary aerocapture technology through a complete mission study. ONERA has been put in charge of the aerothermodynamic investigation considering a CO_2 martian atmosphere. Among conventional Apollo-like capsules and previous MSRO AFE design, an innovative sphero-biconic aeroshape, open on the leeward side, was selected for requiring relevant lift-over-drag ratio with sufficient provision (L/D>0.3), launcher layout constraints compatibility, good provisional payload thermal protection and safely jettisoning after the aerocapture phase. The analysis of three representative and characteristic Mars aerocapture trajectory points results in building an AeroThermoDataBase, including wake flow interaction with the payload and both convective and radiative heat flux estimate achieved by coupling 3D Navier-Stokes assuming CO_2 species non equilibrium and Monte Carlo radiative heat transfer computations. Zones of maximum heating and the associated flux values are assessed and this study confirms previous MSRO findings with significant radiative contribution on the payload. The heating of the rear surface of the satellite, into the open bay, is mainly driven by IR radiation of the wake flow.

Influence of Martian Atmospheric Cycles on Damkohler Numbers Height Profiles

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Diurnal and seasonal cycles of temperature, pressure and density of the Martian atmosphere are very strong. These variations over a Sol and Martian year at a height of 100 km along the equator, according to the Mars-GRAM 2010 atmospheric model, are shown in the Figure 1.

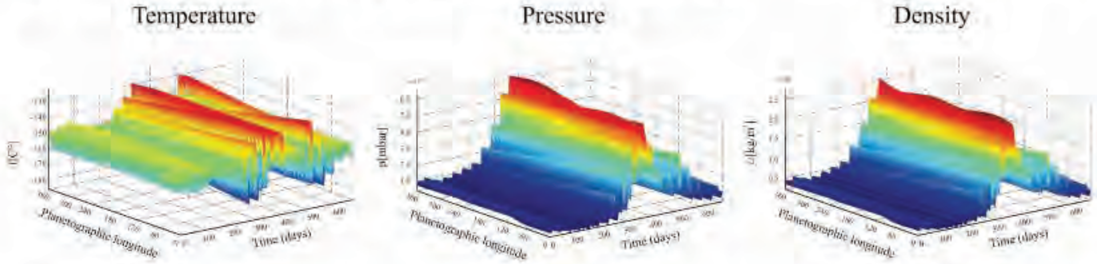

Figure 1 – *Variation of the Martian atmospheric parameters at a height of 100km along the equator*

These atmospheric variations can influence a vehicle velocity profile and flow field variables and consequently influence the thermo-chemical regimes which are represented with Damkohler number height profiles as it is shown in the Figure 2 (Muylaert J, ed. 1997. Capsule Aerothermodynamics, AGARD Report 808).

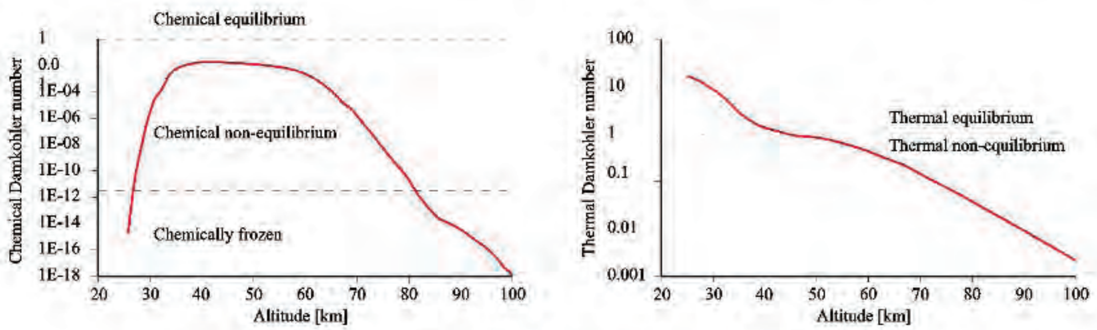

Figure 2 – *Marsnet Chemical and Thermal Damkohler numbers height profiles*

This poster presents a brief analysis of the influence of the atmospheric variations on thermal and chemical Damkohler numbers and their height variation. The obtained results show qualitative and quantitative influence of areocentric celestial longitude of the Sun and sub-solar point coordinates on the boundaries of equilibrium, non-equilibrium and frozen flow regimes.

An ultra-miniaturised XRD/XRF instrument for in situ analysis of planetary surfaces

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Among the potential innovative instruments for future planetary missions, we propose an ultra-miniaturized X-rays diffractometer/fluorescence instrument aimed at the mineralogical and chemical characterization of the surface soils/rocks. Although X-rays diffraction and fluorescence cannot be considered as novelty techniques in the field of mineralogy, the newness of this instrument is the capability of simultaneously measuring X-rays diffraction (XRD) and fluorescence (XRF) patterns and would allow us to disclose the mineralogy and chemistry of planetary soils/rocks. The complete characterization of planetary soils/rocks would indeed help us unraveling many doubtful points regarding the composition and origin of pristine materials and the geochemistry of weathering processes occurring at the planet surface. Based on this concept, an instrument, MARS-XRD, has been already developed and included in the Pasteur payload of the ExoMars mission to Mars [1,2]. MARS-XRD is built by Thales Alenia Space Italia in Milan and the Space Research Center of the University of Leicester. The robustness of the design and the small mass/volume (~1.5 kg and 22x6x12 cm^3), make this instrument suitable for a small lander deployed by a probe mission as well.

MARS-XRD consists of a radioisotope as source of X-rays, a collimator and a CCD-based detection system. The instrument follows a fixed reflection geometry to fulfill the diffraction principle. The advantage of implementing a radioactive source (^{55}Fe and ^{241}Am have been fully tested at the breadboard level) for X-rays generation is power saving, as compared to the X-rays tubes, commonly used for laboratory versions of diffractometers. XRF and XRD measurements are acquired simultaneously and separation of the two types of information is achieved via software. At the time we are writing, the prototype version of MARS-XRD has been developed together with the structural and thermal model (STM) (Figure 1) and the engineering model of the main electronics [Adami et alii, this conference].

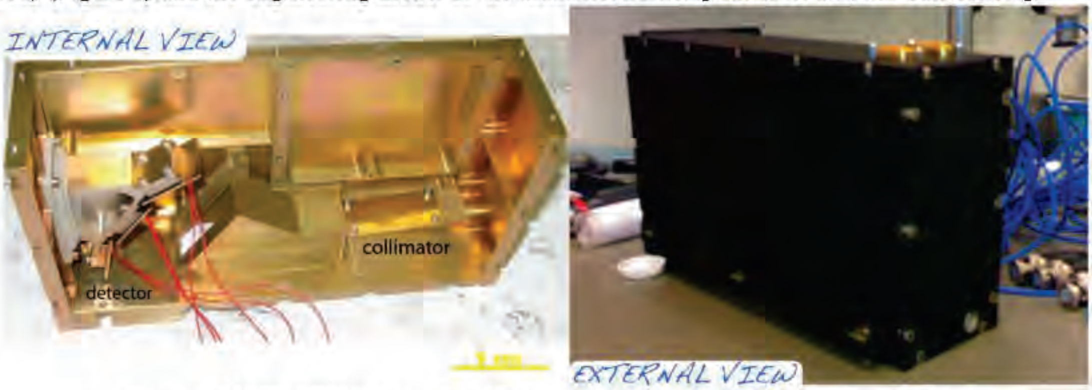

Figure 1. MARS-XRD Structural and Thermal Model (STM) developed at TASI-Milan.

References: [1] Marinangeli et al. (2007) *LPS XXXVIII*, Abstract #1322. [2] Marinangeli et al. (2011) *EPSC-DPS.*, Abstract #1232.

CHEMCAM: AN INSTRUMENT FOR IN SITU ANALYSIS OF PLANETARY SURFACE COMPOSITION.

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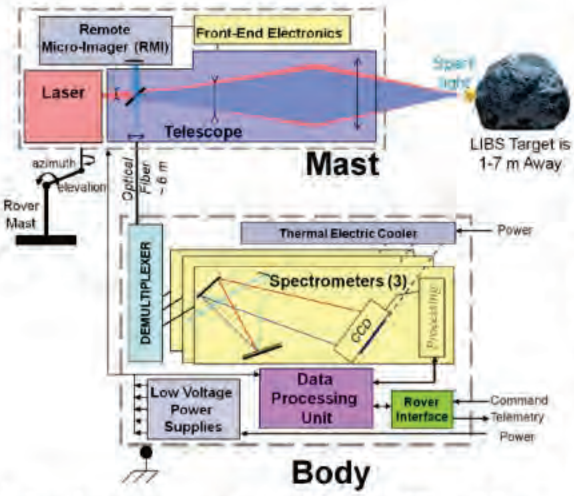
True exploration field geology of the solar system planetary bodies has already begun in the past recent years. To characterise the encountered geologic units, instruments have been developed to provide data on the composition of the surface materials and henceforth a glimpse at the history of the planetary body. Recently new methods of observations have been proposed to investigate details of the Martian geochemistry; they capitalise on the development of laser devices which fit the space travel conditions and sustain the planetary surface environment. In this presentation, the Laser Induced Breakdown Spectroscopy (LIBS) method will be presented and the LIBS based Chemcam instrument will be described (Wiens et al., Maurice et al., Space Science Review, to appear 2012).

The LIBS technique involves firing a focused, pulsed laser beam at targets to excite a light-emitting plasma. Spectral analysis identifies elements, and provides quantitative elemental analyses. Typical spot size on a target is ~350µm in diameter. In combination with a co-aligned high resolution micro-imager (RMI), the knowledge of the exact position of this spot allows identifying the mineral context of the measurement. LIBS analyses yield elemental compositions typically for H, Li, Be, B, C, N, O, F, Na, Mg, Al, Si, P, Cl, K, Ca, Ti, V, Cr, Fe, Ni, Zr, Rb, Sr, As, Ba, and Pb in general with detection limit from 100 to 1000 ppm. LIBS is particularly sensitive to the alkali and alkali earth elements, with some detection limits down to ~1 ppm at close range. On the other hand, remote LIBS is poorly sensitive to halogens, with detection limits for F, Cl, S, and P in the range of several wt.%. In the martian environment, C, N, and O abundances have interferences from atmospheric constituents, raising the C detection limit to ~2 wt. %.



CHEMCAM (PI R. Wiens, Co-PI S. Maurice) is such an instrument on board the rover Curiosity of Mars Science Laboratory (MSL) mission. It uses a laser wavelength of 1067 nm, and provides an energy of 14 mJ per pulse on the target; this allows injection of > $1GW.cm^{-2}$ per pulse at a frequency of 10 Hz, in the target at distance between 2 m and 7 m. The MSL mission is under the responsibility of JPL/Caltech. It has been launched on Nov. 26, 2011 and the landing will occur on August 6 2012.

Other opportunities are under study with the goal of adapting the laser device to larger ranges of operating temperatures as could be necessary on Venus or the Moon, or to implement complementary functionalities such as laser induced fluorescence spectroscopy (LIF) and Raman spectroscopy. The main advantage of these methods is that they are fast and very flexible. As a consequence, they will probably become a standard element of the scientific payload of in situ planetary exploration missions.

Accurate Entry Guidance for a Mars Precision Landing

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ABSTRACT

A major issue for a scientific space exploration mission is to deliver its payload safely and accurately at the predefined landing site. For a Martian mission, the main difficulty comes from the unknown environment of Mars, the weak atmospheric density and the absence of Navigation updates means during the entry path. The ESA-funded "Mars Precision Lander" program which is part of the Mars Robotic Exploration Preparation, or MREP, program specifies an accuracy at touchdown better than 10 km. This mission requirement imposes guiding the Entry vehicle during the Martian Hypersonic Entry phase. Because the descent phase includes a phase under parachute (the final propelled descent phase enabling a soft landing is engaged only around 1 km AGL), it implies also to limit the position accuracy at chute deployment well below this value. Additional constraints expressed mainly towards the chute deployment conditions (not below 6 km AGL for a safe final descent phase) make mandatory to rely on a very efficient and accurate guidance scheme able to manage low braking capabilities on Mars.

Recent ESA-funded studies ("Robust Skip Entry" program) succeeded in the design of such guidance scheme able to perform short to long range entry missions on Earth using the skip entry technique when required. In order to meet the Mars Precision Lander mission requirements, this so-labelled Enhanced Guidance Algorithm whose core technique is a predictor-corrector with a numerical prediction process has been re-used because yielding the most promising performance but also re-engineered to minimize the deviations at the chute deployment. The GNC performance is assessed from the Entry gate down to the lander touch-down in a 3 DOF simulation environment with simplified Navigation and Control performance models. The obtained results summarized on this poster demonstrate, via quasi end-to-end Monte-Carlo simulations, the accuracy of this Skip Entry Guidance scheme applied to a direct entry on Mars and its ability to manage efficiently the low and short braking capabilities of a capsule on Mars.

Session 6A: Cross-Cutting Technologies I

Z. Putnam (Student) : Drag Modulation Flight Control for Planetary Aerocapture Systems

Drag Modulation Flight Control for Planetary Aerocapture Systems

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Hypersonic inflatable aerodynamic decelerators have the potential to enable a broad spectrum of next-generation planetary aerocapture missions by lowering vehicle ballistic coefficient while still meeting launch vehicle shroud constraints. The lightweight nature and small packed size of hypersonic inflatable aerodynamic decelerators, as well as the benign aerothermal environment produced by low ballistic coefficient vehicles largely decouple spacecraft design from the aerocapture system. This greatly simplifies spacecraft design, reduces the need for short-timeline deploy events after the atmospheric pass, and may eliminate the need for cruise stages.

Hypersonic inflatable aerodynamic decelerators provide new options for flight control during planetary atmospheric flight, such as drag modulation. Drag modulation is an attractive flight control option for these low ballistic coefficient vehicles because only minimal additional system complexity is required, in contrast to more conventional lift-modulation methods. Drag modulation allows vehicles with flexible inflatable decelerators to fly at zero angle-of-attack, removing significant uncertainty associated with asymmetric flight of a flexible structure. Drag modulation also eliminates the need for potentially complex effector systems to change bank angle or angle-of-attack during atmospheric flight.

This study considers drag modulation flight control systems for aerocapture using staged drag area jettison events. Potential aerocapture missions at the Earth, Venus, Mars, and Titan were examined. A guidance algorithm was developed and used to evaluate the feasibility of real-time targeting of apoapse altitude during flight. Uncertainty analyses were conducted to determine the robustness of the guidance algorithm and to characterize terminal state dispersions. Results indicate that sufficiently large ratios of maximum to minimum ballistic coefficient provide adequate aerodynamic and guided corridors for a range of future planetary aerocapture missions.

The Hypersonic Inflatable Decelerator (HIAD) Mission Applications Study

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The objective of the HIAD Mission Applications Study is to quantify the benefits of HIAD infusion to the concept of operations of high priority exploration missions. Results of the study will identify the range of mission concepts ideally suited to HIADs and provide mission-pull to associated technology development programs while further advancing operational concepts associated with HIAD technology. An overview of the study plan is presented including a summary of design reference missions. Results from the first iteration of analyses are also presented, which considers HIAD applicability to Earth entry and aero capture from L2 as well as direct entry to the Mars Southern Highlands.

Mass Model Development for Conceptual Design of a Hypersonic Rigid Deployable Decelerator

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As the required payload masses for planetary entry systems increase, non-traditional entry vehicle decelerator systems are becoming a topic of interest. With this interest comes a growing need for the capability to characterize the performance of such decelerators at the conceptual design level. Rigid deployable decelerators are one of these technologies, which entail the use of rigid structures that are retracted for launch and deployed during the entry sequence with the purpose of increasing vehicle drag area. This work develops a first-order mass model for fully rigid deployable hypersonic decelerator systems. The rigid decelerator system is modeled conceptually as a monocoque, ring-stiffened conical frustum which functions as an extension to the forebody of a blunt body, forming a sphere-cone outer mold line when combined with the aeroshell. Its configuration is parameterized in terms of the vehicle attachment diameter and angle, the maximum diameter of the decelerator, and the material properties of the decelerator. In developing this model, analytical relations are developed and empirically modifiedbased on a correction curve from Finite Element Analysis. The resulting relations have been shown to predict failure loads to within 12% of expected results. When combined with aerodynamic and trajectory models, the developed analytical methodology can be used to analyze performance through the use of a rigid decelerator system and can be applied over a wide range of entry conditions, decelerator geometries, and material properties for rapid design space exploration or trade study analyses. In addition, the methodology's use may be extended to study more general aerospace structures such as aeroshell forebodies. As a design example, the developed methodology and resulting relations are applied to analyze a C/SiC hot structure decelerator at Mars for comparison to the performance of the Hypersonic Inflatable Aerodynamic Decelerator concepts presented in a recent EDL-SA study. These results show that the performance of a rigid deployable structure can be comparable to that of a Hypersonic Inflatable Aerodynamic Decelerator at high entry ballistic coefficients and small decelerator diameters.

Simulation of IRVE-3 Flight Dynamics

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The Inflatable Re-entry Vehicle Experiment 3 (IRVE-3), scheduled for May 2012, is designed to subject a 3 m hypersonic inflatable aerodynamic decelerator (HIAD) to a peak heat flux above 12 W/cm^2. The vehicle is placed on a suborbital trajectory by a Black Brant XI three stage sounding rocket, and after inflation of the aeroshell, reenters the atmosphere at approximately Mach 9. The test vehicle is designed to fly with lift generated from a laterally offset center of mass, with control jets to maintain the desired vehicle orientation through the end of the experiment at Mach 0.7. Nominal and dispersed trajectory simulations provide the expected range of structural loading and aerothermodynamic conditions the vehicle encounters during the experiment. Aspects of atmospheric entry especially significant to HIAD's are examined, such as aeroelastic effects on flight conditions and attitude control in the presence of aeroshell structural modes.

Surface Catalyzed Reaction Efficiency Measurements for Flexible TPS Materials

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A new approach to measuring surface-catalyzed recombination reactions on candidate thermal protection system (TPS) materials is presented. Measurements are performed in a recently constructed 30 kW Inductively Coupled Plasma (ICP) Torch Facility at the University of Vermont. Samples are mounted in stagnation point configuration and laser spectroscopic measurements of translation temperature and species concentration are made in the reacting zone above the material surface. Two-photon LIF is used to measure concentrations of nitrogen and oxygen atoms flowing toward the surface, and a simple diffusion model is used to infer the surface-catalyzed reaction efficiency based on the concentration gradients. Measurements are conducted with different plasmas to assess the different surface-catalyzed reactions. Nitrogen plasma is used to determine nitrogen atom recombination, and an air plasma flow is used to determine oxygen atom recombination efficiency. Finally, direct detection of NO formation near the surface using single photon LIF is performed to determine the efficiency of heterogeneous recombination, which competes with homogeneous recombination in air plasmas.

Inflatable atmospheric entry decelerators are currently being developed with blanket TPS materials to deal with aerothermal heating during atmospheric entry, and the above laser-based technique has been extended to assess surface-catalyzed reaction efficiencies for flexible TPS samples. The measurements rely on comparison with measurements of solid samples made from the same base material, and use of the solid sample as a backing substrate for the flexible material.

Results will be presented for nitrogen atom recombination on solid SiC, with preliminary measurements of oxygen atom recombination and an assessment of NO production. Preliminary results for the flexible material will also be presented.

Novel Computational Simulations of Inflatable Aerodynamic Decelerators during deployment

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Planetary exploration missions' architectures that use Inflatable Aerodynamic Decelerators, IADs, are being studied by NASA, ESA and their partners in order to allow future spacecraft land on destinations with an atmosphere delivering a heavier payload than currently attainable. These devices are packaged in a low volume configuration, thus allowing use of current launch vehicles and deployed (inflated) during entry or descent depending on the particular type employed, e.g. hypersonic or supersonic IADs.

The proposed research examines this technology and performs detailed novel analysis of the behavior during the deployment phase at different atmospheric conditions. Computational simulations are presented where fluid-structure aeroelastic interactions are determined by coupling the results from high fidelity structural and fluid analysis software. The configurations analyzed; tension cone and isotensoid, match those of efforts performed elsewhere and reported in literature.

The simulation allows analysis of a mesh representing the stored IAD, its expansion as an inflation device releases compressed gases and its interaction with aerodynamic forces. Successful determination of the loads and behavior of the IAD will allow safe and efficient spacecraft designs that can accomplish the desired mission goals.

Application of High Pressure Textile Inflatable Structures for Planetary Probes

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Abstract

The development of high pressure braid reinforced inflatable structures has advanced the capabilities of deployable structures that require low mass, stowed volume efficiency, and reliable deployment. Rigid composite structures that use fibers to provide tensile strength and a resin matrix to provide compressive strength are extremely mass efficient but not effective when the structure must be stowed during transport and then deployed on station. Flexible composite structures also employ fibers as tension elements but use inflation pressure to provide compressive strength eliminating the need for the rigidity of the composite structure's resin matrix. Inflatable structures can be packed at densities similar to parachutes and have flexible coatings and adhesives that maintain the flexible structural-elements alignment while packed.

AirBeam technology was originally developed for rigidizing parafoil type parachutes, but its potential for use in terrestrial applications and inter planetary missions was quickly realized. The use of Airbeams for terrestrial habitats has been extensively pursued with numerous examples being used for many different applications. Elements of these structures could be applied to future use for habitat for manned planetary missions and as deployable habitat modules for space craft. Furthermore, AirBeams have been used in the design of inflatable wings for planetary research airplanes and for deployable high altitude reconnaissance aircraft. Inflatable tori are actively being developed for use in Inflatable Aerodynamic Decelerators, providing decelerations during initial atmospheric entry not previously available to current entry vehicles. This paper will discuss the advancement of Airbeam technologies for planetary missions - including the design methodology, finite element modeling techniques, and verification testing.

Analysis of Fluid-Structure Interactions with Application to Inflatable Aerodynamic Decelerators

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The recent launch of the Mars Science Laboratory (MSL) will push the limits of deceleration technology as the vehicle enters the Martian atmosphere in August 2012. All Mars entry systems to date have relied heavily on the technology developed for the Viking Missions of the 1970s. Future missions will require increased landing mass, as well as higher precision landing capabilities. In order to achieve these goals, extensive technological development of deceleration concepts beyond the traditional disk-gap-band (DGB) parachute is necessary. Alternative systems had been considered during the development of the Viking program, but due to the decision to utilize the DGB, minimal research followed. The last decade has seen a renewed interest in developing necessary alternatives with one such enabling technology being the inflatable aerodynamic decelerator (IAD).

With the impracticality of flight-testing every configuration for various conditions, and the problems associated with scaling wind tunnel tests, reliable computational simulations are critical. Recent work by a number of investigators[1,2,3,4] has focused on the development of computational modeling for this problem. Much, but not all, of the work has been focused on the static analyses of the coupling between the fluid flow and structural dynamics. That being said, the goal of the present work is to develop a time-accurate aeroelastic tool to model the fluid-structure interactions (FSI) of inflatable aerodynamic decelerators.

FSI simulations require the computational analysis of both the fluid and structural dynamics. The current approach for joining the two disciplines utilizes a loose-coupling methodology between NASCART-GT and LS-DYNA. The fluid dynamics is solved using NASCART-GT, a solution adaptive, Cartesian grid-based, Navier-Stokes solver. A significant benefit of using this tool includes its capability to perform automated grid generation over complex, three-dimensional geometries. In addition to eliminating manual grid generation, this feature provides the framework for which the grid is adapted as the geometry undergoes deformation. Unlike body-fitted meshes that have limits on their ability to undergo deformation, such motion is more readily handled by an unstructured Cartesian grid. The structural analysis takes advantage of the commercial software package, LS-DYNA. This tool is a nonlinear, finite element solver that has been demonstrated[1,4] as a reliable tool for analyzing thin-filmed, deformable membranes such as the configurations of interest in this study.

A series of validation cases are examined for both solvers. The re-gridding process that is associated with geometry deformations in NASCART-GT is verified for two moving cylinder test cases. These tests also provide validation of the moving boundary condition implementation by investigating surface pressure distribution. Additionally, a study of the time accuracy in the presence of unsteady boundary conditions is presented. This is achieved by investigating the case of a piston that is accelerating into and away from a stationary fluid. A relevant LS-DYNA case is also presented as a means of augmenting previously published validation cases. Finally, the analysis of an inflatable aerodynamic decelerator is presented. This case demonstrates the implementation of FSI coupling for a static analysis, which will lay the groundwork for further investigation of dynamic aeroelastic simulations.

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[1] Rohrschneider, R. R., *Variable-Fidelity Hypersonic Aeroelastic Analysis of Thin-Film Ballutes for Aerocapture*. PhD Thesis, School of Aerospace Engineering, Georgia Institute of Technology, 2007.
[2] Clark, I. G., *Aerodynamic Design, Analysis, and Validation of a Supersonic Inflatable Decelerator*. PhD Thesis, School of Aerospace Engineering, Georgia Institute of Technology, 2009.
[3] Gidzak, V. M., *A Method of Simulating Fluid Structure Interactions for Deformable Decelerators*. PhD Thesis, University of Minnesota, Minneapolis, MN, 2010.

[4] Tanner, C. L., *Aeroelastic Analysis and Testing of Supersonic Inflatable Aerodynamic Decelerators*. PhD Thesis, School of Aerospace Engineering, Georgia Institute of Technology, 2012.

Commercial Crew Vehicle Parachute and Airbag Testing

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As part of the NASA Commercial Crew Development (CCDev) program, the Boeing Company is developing an Apollo type capsule that will be used to ferry crew and cargo to the International Space Station. Boeing's concept for landing and recovery is based on land landings as the primary landing mode using airbags and a parachute system very similar to that developed for the Apollo program. The capsule will also be capable of contingency water landing if necessary. The airbag landing attenuation system that Boeing is developing leverages work previously done by the NASA Langley Research center (LaRC) under the Advanced Development program (ADP).

The paper will present the results of both the airbag and parachute full-scale development testing conducted during Phase 2 of the NASA CCDev program. The Airbag testing portion of the paper will describe activities leading up to and the results of tests conducted on dry lake beds in California and New Mexico, at a site similar to the Edwards Dry Lake Bed, one of the primary landing sites for the operational CST-100 (Commercial Space Transpiration), and at the Alkali Flat where the Space Shuttle landed at the White Sands Missile Range (WSMR), the other planned landing site.

The paper will also describe a parachute drop test conducted at a remote location in Nevada, on BLM land, and located within the airspace of the Nellis Airforce Range. The parachute test involved a full scale prototype of the CST-100 vehicle and incorporated a total of 8 parachute; 2 mortar deployed drogue parachutes, 3 mortar deployed pilot chutes, and 3 large main parachutes in order to slow the vehicle prior to airbag inflation and landing.

Each section described will include test planning, test article design and fabrication, computer modeling and simulation, test activities, test data reduction, and model correlation.

Conformal Ablative Thermal Protection System for Planetary and Human Exploration Missions:

An overview of the Technology Maturation Effort Funded by NASA's Game Changing Development Program

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The Office of Chief Technologist (OCT), NASA has identified the need for research and technology development in part from NASA's Strategic Goal 3.3 of the NASA Strategic Plan to develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable. Furthermore, the Game Changing Development Program (GCDP) is a primary avenue to achieve the Agency's 2011 strategic goal to "Create the innovative new space technologies for our exploration, science, and economic future." In addition, recently released "NASA Space Technology Roadmaps and Priorities," by the National Research Council (NRC) of the National Academy of Sciences stresses the need for NASA to invest in the very near term in specific EDL technologies. The report points out the following challenges (Page 2-38 of the pre-publication copy released on February 1, 2012):

> *"**Mass to Surface:** Develop the ability to deliver more payload to the destination. NASA's future missions will require ever-greater mass delivery capability in order to place scientifically significant instrument packages on distant bodies of interest, to facilitate sample returns from bodies of interest, and to enable human exploration of planets such as Mars. As the maximum mass that can be delivered to an entry interface is fixed for a given launch system and trajectory design, the mass delivered to the surface will require reductions in spacecraft structural mass; more efficient, lighter thermal protection systems; more efficient lighter propulsion systems; and lighter, more efficient deceleration systems.*
>
> ***Surface Access:** Increase the ability to land at a variety of planetary locales and at a variety of times. Access to specific sites can be achieved via landing at a specific location(s) or transit from a single designated landing location, but it is currently infeasible to transit long distances and through extremely rugged terrain, requiring landing close to the site of interest. The entry environment is not always guaranteed with a direct entry, and improving the entry system's robustness to a variety of environmental conditions could aid in reaching more varied landing sites."*

The National Research Council (NRC) Space Technology Roadmaps and Priorities report highlights six challenges and they are: 1) Mass to Surface, 2) Surface Access, 3) Precision Landing, 4) Surface Hazard Detection and Avoidance, 5) Safety and Mission Assurance, and 6) Affordability. In order for NASA to meet these challenges, the report recommends immediate focus on Rigid and Flexible Thermal Protection Systems.

Rigid TPS systems such as Avcoat or SLA are honeycomb based and PICA is in the form of tiles. The honeycomb systems is manufactured using techniques that require filling of each (3/8" cell) by hand and within a limited amount of time once the ablative compound is mixed, all of the cells

Characterization of innovative carbon/composite ablators for future space exploration missions in reentry environments

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Following the current developments of a new class of low-density, carbon/resin composite ablators for future space exploration missions, new efforts were initiated at the VKI on ablation research to better understand the complex material response under reentry conditions and to develop new material response models. This necessitates ablation tests in combination with microscopic analysis tools (SEM/EDX) for sample examination at the carbon fiber length scale (~10 µm).
A low-density carbon fiber prefom felt (without phenolic impregnation) was tested in the 1.2MW Plasmatron facility at varying static pressures from 15.0-200 mbar at a constant cold wall heat flux of 1 MW/m^2, resulting in surface temperatures of around 2000 K. This preform is similar to the precursor for the European ablator ASTERM (EADS Astrium ST) and similar to PICA's FiberForm®. It was found that recession and mass loss of the test specimen was highest at low static pressure. Furthermore, high-speed-imaging as well as conventional photography revealed strong release of particles into the flow field, probably assignable to spallation (Fig. 1). Micrographs showed that packages of glued fibers are embedded in-between randomly oriented, individual fibers. It is therefore assumed that ablation of the individual fibers leads to detachment of whole fiber bundles. It was further found that in an ablation environment of 10kPa ablation lead to an icicle shape on a top layer of 250µm of the fibers with constant thinning, whereas at low pressure (15 mbar), the fibers showed strong oxidation degradation over their whole length (Fig. 2). A higher diffusion rate of oxygen at low pressures together with a lower atomic oxygen concentration at 15 mbar (decreasing the fiber's reactivity) may allow oxygen to penetrate into the internal material structure. A comprehensive test campaign on a fully developed low-density ablator, ASTERM (EADS Astrium ST), is planned for spring 2012 at the VKI.

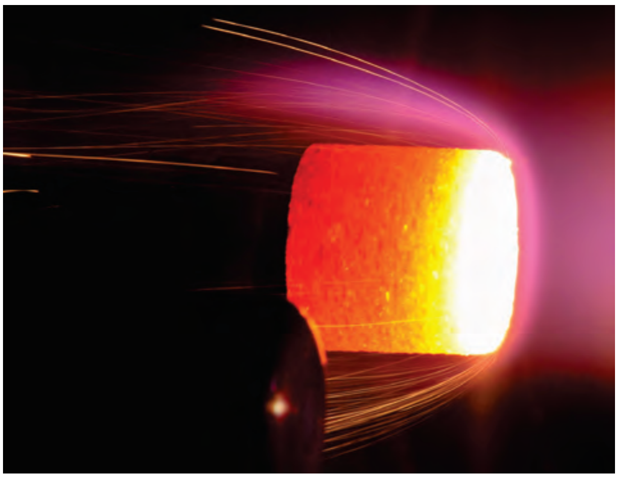

Figure 1: Conventional picture during preform ablation (p_s=100mbar) highlighting bright sparks (exposure time: 5 ms)

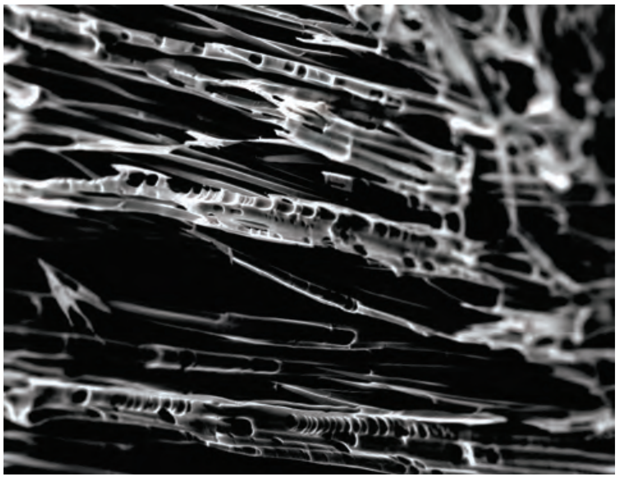

Figure 2: Fiber bundles exposed to the flow at the surface present strong corrosion of fibers throughout their whole length rather than a regular thinning from fiber-top to fiber-bottom.

Session 6B : Earth entry and sample return

W. Huang : Analysis of Minimum Ejection Velocity and Angle Range for Parachute into the Current

Analysis of Minimum Ejection Velocity and Angle Range for Parachute into the Current

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The parachute systems are applied to almost all kinds of recoverable spacecraft and planetary atmospheric entry, descent and landing probes. For parachute systems, the pyrotechnic device, such as catapult or mortar is used to eject the first stage of parachute bag and ensure the success of deployment and inflation. The minimum required ejection velocity and the ejection angle range should be confirmed.

This paper established the ordinary difference equations of the motions of parachute bag and spacecraft in the phase of ejection and separation, focuses the situation of ejecting parachute in the direction of spacecraft velocity. Through input different initial parameters, including the ejection velocity, these equations can be solved, and the displacements of parachute bag and spacecraft can be got, so the distance between them can be analysed. Based the feasible distance assuring the parachute not impacted and opened safely, the minimum required ejection velocity and the range of acceptable ejection angle for parachute can be gained.

The analysis method presented by this paper was testified by examples and can be used in the preliminary design phase for the recovery systems.

Small Probes for Orbital Return of Experiments Mission Design

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Small Probes for Orbital Return of Experiments (SPORE), provides an on-orbit and re-entry platform for a range of biological, thermal protection system (TPS) characterization, and material science experiments. This platform will provide the capability for 1-4 weeks of on-orbit flight operations for experiments with comparable mass and volumes laid out by the 1U, 2U, and 4U cubesat guidelines. The platform will accommodate polar low earth orbit (LEO), geosynchronous transfer orbit (GTO), and ISS-return missions to maximize the science potential. Packaging models and mass budgets were created for the SPORE entry vehicles. In addition, analyses were completed to construct the SPORE mission design. Orbital trajectory and maneuvers were modeled for the ISS, LEO, and GTO missions. A re-entry architecture was designed to meet the requirements set by the range of payloads, orbits, and entry vehicle sizes inherent in the SPORE mission concept. The selected entry, descent, and landing (EDL) architecture was validated and modeled using 3-DOF and 6-DOF software. A thermal soak-back analysis was used to generate a temperature profile for the payload, and a Monte Carlo analysis was completed on this architecture to assess landing footprint. Results from the landing dispersion analysis confirm current landing site selections and help establish recovery procedures.

INTERIM RESULTS OF THE RASTAS SPEAR PROJECT

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ABSTRACT

The RASTAS SPEAR project (http://www.rastas-spear.eu/, FP7/Space/241992) is being carried out under the FP7 framework programme of the European Union with the aim to increase Europe's knowledge in high speed re-entry vehicle technology to allow for planetary exploration missions in the coming decades.

The capability to send vehicles into space, to collect and return to Earth soil samples from solar system bodies, such as the planned "Mars Sample Return" mission, is crucial for our further understanding of the solar system and the universe. To return these soil samples, any mission will end by high-speed re-entry in Earth's atmosphere. This requires a strong technological base and a good understanding of the environment encountered during atmospherere-entry.

The project is carried out by a consortium of European companies and institutes: VKI (B), Kybertec (Cz), Demokritos (Gr), IoA (Pl), CIRA (I), CFS (CH), MSU (Ru), CNRS and ONERA (F), and coordinated by Astrium (F).

The project is now in its final year and many of the objectives have been realised. The purpose of this presentation is to present some of the results obtained and discuss the way forward, especially regarding:

- Aeroshape stability
- High speed aerothermal environment
- Sub-system / equipment : Thermal protection, Crushable material

IPPW-9 - Experimental determination of the dynamic derivatives of the ARV Reentry Module

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EADS Astrium ST

Entry capsules provide an attractive option for planetary exploration missions. Designed to survive during early phases of atmospheric entry, these vehicles often become dynamically unstable at low altitudes. Proper characterization of aerodynamic damping can allow drogue chute deployment at lower Mach number. Such findings may permit smaller drogue chute designs, thus enabling a payload volume and weight increase as well as a vast decrease in drag penalties.

The aerospace vehicle is exposed to unsteady flow fields that may have significant effects on its characteristics of motion. As a result, the dynamic stability information, considered of rather lesser importance for a number of years, has became an object of relatively high interest. The reason is obvious: in the past, for aircrafts at low angles of attack, most of the dynamic stability parameters were relatively easy to predict analytically, exhibited as a rule only smaller variations with varying flight conditions and therefore, had only a relatively insignificant or at least, a relatively constant effect on the resulting flight characteristics of the vehicle. With the advent of flight at high angles of attack at high speeds, all that has drastically changed. The dynamic stability parameters are now found to depend strongly on the non-linear effects and can no longer be calculated using relatively simple linear analytical methods as in the past and new methods are needed.

As the nonlinear instability phenomena are not well known for the moment, it is in general difficult to simulate them using CFD. Thus, the experimental techniques in wind tunnels are certainly the best way to obtain dynamic stability information at realistic Reynolds and Mach numbers.

This project intends to contribute to the construction of the ARV Reentry Module (RM) aerodynamic database in subsonic regime. Specific model and balance were designed and build for the assessment of the static efforts on the vehicles. For the dynamic part, the forced oscillation technique was selected. It is the main challenge of this project. For this purpose a completely new set-up was designed and built. A specific instrumentation will be installed in the model to measure the angle of attack and the forces acting on the model. The damping parameter is deduced from the experiments. The results and its uncertainty will be discussed and a new approach is developed for the validation of the results.

Coupling of blowing and roughness effects in the Spalart–Allmaras turbulence model

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During high speed atmospheric re-entry Thermal Protection System (TPS) can ablate and develop roughness. A review of surface roughness and blowing influence on aerothermodynamics reveal these effects to be significant, and thus it is important to set up an extended model taking both of them into account. The model for a flow in turbulent boundary layer on a rough surface was constructed earlier based on the extension of the Spalart–Allmaras turbulence model[1]. It is known that the Spalart–Allmaras turbulence model describes the boundary layer by considering a one transport equation for the variable similar to turbulent viscosity. The boundary condition on the wall is linked with the wall roughness using Nikuradse law. The other condition is imposed far from the wall in the limit region.

In this study the possibility of taking into account both roughness and blowing in the Spalart-Allmaras model is analyzed. One of the main suggestions of the Spalart–Allmaras turbulence model is the logarithmic velocity profile in boundary layer. This assumption which holds for non-blowing case is replaced by bilogarithmic velocity law in case of blowing[2]. While the initial model suggests that logarithmic law is shifted depending on roughness height, we suppose that the roughness causes the shift of bilogarithmic law in similar way. The possible application of the Spalart–Allmaras turbulence model to consider both roughness and blowing is constructed by modifying boundary conditions and the variables of the base model according to the properties of bilogarithmic velocity profile.

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Earth entry observations: Solution to inverse problem with incomplete data

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While the Earth orbits the Sun, it is subject to impact by smaller objects ranging from tiny dust particles and space debris to much larger asteroids and comets. To study these collisions in more details, and to better understand phenomena during hypervelocity atmospheric entry, we present a practical algorithm connecting ground based observations with the properties of otherwise unknown objects entering the Earth's atmosphere. In particular, we derive analytical dependencies between space object mass, its size and other properties from the rate of body deceleration in the atmosphere. The study is completed by considering luminosity of an object with the approach similar to (Gritsevich and Koschny, 2011)[1]. In addition, we highlight some directions for further studies and potential improvements to the proposed technique.

Characterization of the Entry State Uncertainty for SPORE

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Small Probes for Orbital Return of Experiments (SPORE) provides on-orbit operation and recovery of small payloads. The flight system architecture consists of a service module for on-orbit operations and deorbit maneuvering, and an entry vehicle for atmospheric entry, descent, and landing. Prior to approximating a landing footprint with a Monte Carlo analysis on the entry trajectory, the entry state uncertainties must be characterized. These uncertainties arise from errors induced by the guidance system and thruster pointing control during the deorbit maneuver. In order to capture the effect that these errors have on the entry state uncertainty, the service module's attitude determination and control system (ADCS) and guidance system were both modeled in Matlab. By incorporating the ADCS loop into the guidance loop, the effect of pointing errors during the deorbit trajectory combined with errors in the guidance system can be assessed. A Monte Carlo analysis is performed on this 3+3 DOF deorbit simulation (which terminates at entry interface), resulting in an entry state covariance. The analysis is performed on the three orbits under consideration for SPORE: ISS, LEO, and GTO.

CanSat: multiphysics experimental design of a probe come back mission

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Earth reentry of a space small probe (typical of students' projects) sets the question of guidance and precise landing. In this frame the aim of the present work is to design, to build and to operate a decelerator system that will be automatically controlled by a space probe in order to reach an a priori chosen landing point. This multiphysics project involves at the same time design and fabrication of the decelerator, flight mechanics of the deformable decelerator, guidance and control development of the decelerator by the probe. The project is divided in two parts. The first one aims to design and launch a small probe (33cL/300g) with abilities of both automatic precise landing, and in flight data recording or transmission (pressure and temperature). The "small probe" students'project aims the CanSat challenge, an international competition organized in France by the CNES and Planete Sciences association. The second one is to launch a bigger probe (1L/1kg) from a 1/25th Soyouz Rocket developed by the Samara State Aerospace University (Russia).

One section of this project is the design of a NASA parawing (NPW5). The first goal is to reduce the number of iterations needed to build some prototypes of wings. This is achieved by giving a method for the choice of the design parameters of the NPW5 (size, length of the suspension lines, calibration, materials and fabrication methods) with the characteristics and objectives of the chosen mission. The study uses the wind tunnel of the ISAE and tests in flight to characterize the curves and the spiral stability.

Another section, the one concerned by the reentry problem, is the development of the CanSat's guidance system so as to have a precise landing by using GPS. For this purpose, a five students team has worked with the DGA-TA (which could be translated as "General Directorate for Armament – Technical Aeronautic") to test the guidance system and to make some experiments related to the command and control of the veil. Results of the test are presented. The CanSat already emits each second the recorded data: pressure, temperature, heading and now we are studying different kinds of configurations (number of actuators, suspension lines used to turn...), in order to improve the guidance system.

EntrySat: A Study of the Atmospheric Re-Entry Environment

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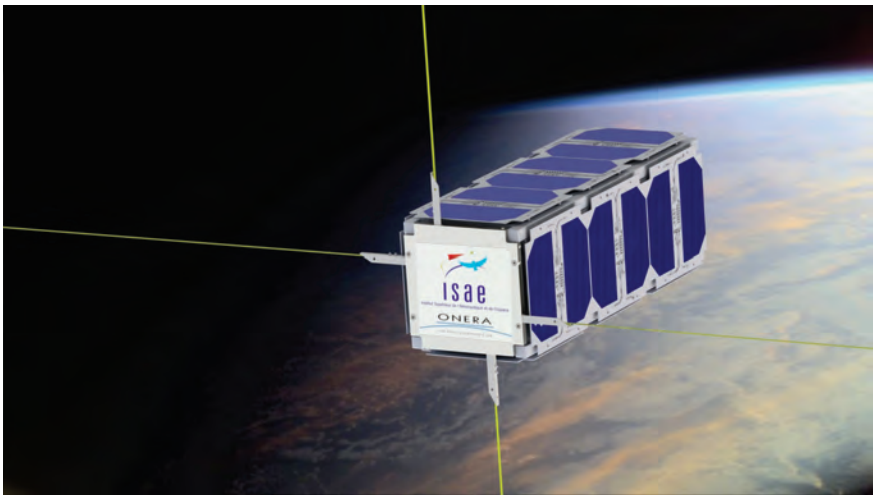
ISAE/SUPAERO

The EntrySat mission is a joint project between the Institut Supérieur de l'Aéronautique et de l'Espace (ISAE), the Office National d'Études et de Recherches Aérospatiales (ONERA), and the Centre National d'Études Spatiales (CNES) to fly a 3U CubeSat under the QB50 competition. The primary objective of the mission is to return data on the atmospheric environment of small objects re-entering the Earth's atmosphere.

To date, several computer models have been tested and verified for larger vehicles and objects entering the atmosphere – however, the re-entry environment and behavior of small objects, such as CubeSats and orbital debris, is relatively underexamined. While the same models are applied to these objects, it is not known entirely whether the models are valid for the flight regime experienced by a CubeSat-sized object.

The EntrySat mission will record temperature data and drag force data during the re-entry event in order to validate re-entry models. The final phase of satellite flight constitutes the primary mission of the satellite – nominal orbital operations will be primarily dedicated to the testing of engineering systems and the maintenance of system health in preparation for re-entry. Data collection for nominal operation, including GPS, absolute attitude, magnetometer, and satellite dynamics via on-board IMU, will continue until destruction so that temperature and drag force data may be correlated to the satellite orientation and trajectory. Communication provisions will be made through the use of alternative networks such as the Iridium constellation, in addition to UHF/VHF radio to ensure that data is returned.

This project is intended to fly as an In-Orbit Demonstration (IOD) satellite for the QB50 constellation. The satellite shall be designed, built, and tested by students at ISAE, in collaboration with ONERA and CNES.



Design of the SPORE Small Probe High Altitude Balloon Drop Test

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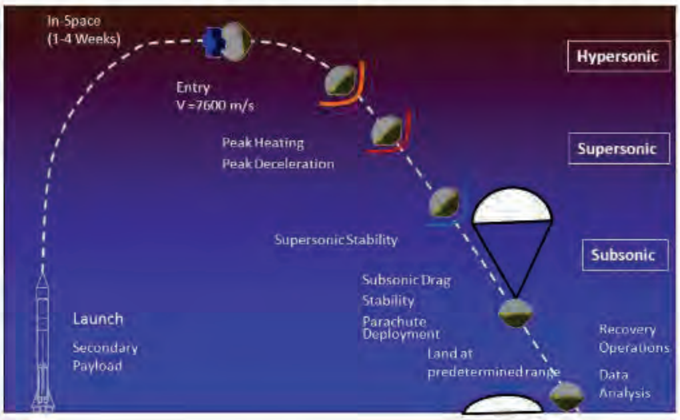
Various platforms for launching small, Earth-orbiting payloads are currently available, but there exists a need for an affordable, standardized re-entry and recovery system for these CubeSat class payloads. Recovering the payload is valuable for a multitude of biological and materials science payloads, where samples can be further analyzed in a ground-based laboratory. In addition, exposing the recovery probe to the Earth re-entry environment can provide a valuable Thermal Protection System (TPS) testbed, providing relevant flight data for comparison to ground-based arcjet tests.

The SPORE (Small Probes for Orbital Return of Experiments) concept seeks to provide the capability to recover CubeSat class payloads, ranging in size from 1U to 4U. The SPORE flight system would interface with a standardized lightband launch vehicle adapter as a secondary payload, and would be capable of exposing the payload to the microgravity and radiation environments of low-Earth orbit, GTO, and with docking and deployment from the ISS. In addition, the SPORE flight system also allows for the testing of TPS materials in a flight-like environment, with capabilities for TPS instrumentation data storage and heat shield recovery after re-entry. The figure to the right shows a diagram of the SPORE mission concept.



The following paper will detail the design of a high-altitude balloon test program being developed to demonstrate critical functions of the SPORE entry system. In particular, the balloon drop test program will seek to verify system functionality, such as the subsonic parachute deployment and triggering system, the payload beaconing device, and payload data recording hardware. The test will also provide invaluable experience with the ground and recovery operations. These and other factors considered in the drop test program will be covered in the associated paper.

Development of Precision Parafoil Flight at Very High Altitude For Sample Return Applications

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The design and development of a unique high-altitude controlled parafoil is described. The design uses a GPS-based targeting methodology developed in conjunction with San Jose State University, NASA Ames Research Center, and the Naval Post Graduate School (NPS). The control system uses a precision targeting algorithm that promises a potential of better than 100 meter accuracy, and is in development with low altitude tests by NPS. The results from balloon deployment tests at increasing altitude – to 30km – are described. In addition, the basic aerodynamics of a parafoil at low dynamic pressure and Reynolds number are thus far regarded as unique. Potential advantages of the design are (a) greater ground-targeting range enabled by deploying the parafoil at such high altitude, and (b) the ability to correct for minor targeting errors when used as the terminal descent phase of a planetary atmospheric entry system. A proposed terrestrial application for the parafoil system is the terminal stage of the Small Payload Quick Return (SPQR) system, which would accurately return 4.5L of temperature-controlled specimens from the International Space Station (ISS). Other applications may include the improvement of terminal precision targeting for small Mars missions, which would experience comparable aerodynamics.

CHARACTERIZING AN EXPERIMENTAL DECELERATOR FOR DELIVERING NANO-SAT PAYLOADS TO PLANETRY SURFACES

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ABSTRACT

NASA Ames Research Center is developing the Small Payload Quick Return (SPQR) system, designed to quickly deliver a small payload from the International Space Station (ISS). The SPQR system uses a unique atmospheric drag device which makes it compatible with crew operations. A crew member would release the system from the ISS. The atmospheric drag device would deploy, and de-orbit the system in roughly 40 orbits. A tube deployed re-entry vehicle would then allow the payload to enter the atmosphere. At an altitude near 30,000 meters (95,000 feet), a parafoil system would deliver the payload to the surface of Earth. In order to improve the accuracy of the targeting system over the gradual de-orbit process, it was necessary to develop an on-orbit position determination system. A Short Burst Data (SBD) modem offered by satellite phone vendors is to be tested to determine the viability of the uplink/downlink capability. This modem will include a GPS receiver and will transmit its location multiple times per minute, throughout the entire de-orbit period. The position resolution will help accurately characterize the aerodynamics of the atmospheric drag device throughout entry and descent.

The University of Idaho's Near Space Engineering program has worked with NASA Ames to test various subsystems for the SPQR system. To support the test of the Ames SPQR system, a telecomm system for telemetry comprising of an SBD modem and sensors was successfully flown on a weather balloon to an altitude above 27,000 meters (90,000 feet) in October 2011. The next balloon test of the telemetry system will include position determination, and is scheduled for spring 2012. These tests will culminate with a trip to space aboard the Antares' maiden launch, scheduled for August 2012 from NASA Wallops Flight Facility, as well as a similar experiment to be jettisoned from the ISS in September 2012. Further testing of the SBD modem is required, and then an Earth entry and descent test can be conducted. Once the atmospheric drag device is properly characterized and tested, the SPQR system could be used to deliver Nano-sat scale payloads to the surface of Mars.

PROMOTING SAMPLE RETURN MISSIONS FROM UNDIFFERENTIATED BODIES

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Several sample return missions, like Osiris-Rex (NASA) or Marco Polo-R (ESA), are currently ongoing or being evaluated to achieve *in situ* sampling of undifferentiated bodies in the next future. Such missions have the main goal to bring back to Earth pristine samples to get clues on the formation, and environment conditions in which their parent bodies formed and evolved from the protoplanetary disk materials. It is not an easy task as many chondritic asteroids and periodic comets have been subjected to important collisional and space weathering processes since their formation. Their surfaces have been reworked by impacts as suggest the brecciated nature of many chondrites arrived to Earth that have suffered different levels of thermal alteration. On the other hand, the degree of thermal metamorphism and aqueous alteration experienced at early stages of parent body formation in the different chondrite groups is highly variable. Consequently, having so many factors against us, we find it necessary to develop strategies to identify good candidates, and once visiting them, to pick up the best regions for having real success in sampling pristine materials.

To gain insight in this subject we are currently studying primitive chondrites by different techniques. The most pristine carbonaceous chondrites (CCs) have been less affected by thermal metamorphism and aqueous alteration in their parent bodies. Both aspects are crucial in order to get samples representative of the conditions in which their forming materials condensed in the nebula, and also capable to contain significant amounts of presolar grains. Our study is being completed by analyzing carbonaceous chondrites from the Antarctic NASA collection, plus other CC exemplars from private or public collections. In general, pristine CCs can be considered quite rare in meteorite collections. Certainly our sample is biased towards high-strength materials capable to survive million years-long residence times in the interplanetary space, and atmospheric interaction during their entry. In any case, several groups of chondrites contain a few members with promising properties to study solar system formation conditions. The CI and CM groups suffered extensive aqueous alteration, but for the most part escaped thermal metamorphism (only a few CMs evidence heating over several hundred Kelvin). In fact, the CI and CM chondrites are water-rich, and secondary minerals as consequence of the pervasive alteration of primary phases are common. CO, CV, and CR chondrite groups suffered much less severe aqueous alteration, but some CRs are moderately aqueously altered. CO and CV groups are good candidates to find presolar grains as they experienced moderately small heating. Thermal metamorphic grades for both groups are ranging from low (3.0) to nearly type 4. One would be the CO chondrite ALHA77307, another is the CM-like ungrouped Acfer094. To find pristine chondrites among the different groups of ordinary chondrites is more complicated, but some examples exist like e.g. LL3.0 Semarkona, and LL3.1 Bishunpur.

Our main goals are: 1) To identify solar system pristine materials, and their parent bodies; 2) To understand the main biasing factors of these materials in interplanetary space; 3) To perform new experiments and develop new techniques for comparing reflectance spectra of asteroids with UV-V-IR laboratory spectra of pristine meteorites. Consequently, we wish to better identify the parent candidates, and the best collecting areas in their surfaces to increase the chance of returning really pristine samples.

Flight Performance of the Inflatable Reentry Vehicle Experiment 3 (IRVE-3)

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The Inflatable Reentry Vehicle Experiment 3 (IRVE-3) is scheduled to launch from NASA Wallops Flight Facility in May 2012. IRVE-3 is intended to demonstrate the reentry survivability of a hypersonic inflatable aerodynamic decelerator in a flight environment with reentry heating over 10 W/cm^2, and to demonstrate the effect of an offset center of gravity on the flight L/D.

This paper discusses the IRVE-3 mission scenario and predicted performance and compares them to the as-flown trajectory of the launch vehicle and reentry vehicle. The reentry vehicle design and flight performance are discussed with comparison of pre-flight data to the flight performance of the inflation system, and predicted versus measured temperatures on the inflatable aeroshell. Lessons learned from IRVE-3 subsystem performance are documented for future use, and plans for eventual mission use of inflatable aerodynamic decelerators are discussed.

Aeroheating test of entry capsule models in high-enthalpy and high-pressure flow

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Key Words : Heat flux measurement, Reentry capsule, Hypersonic, Shock tunnel

Abstract

Although the numerical simulation has made remarkable progress in last few decades, accurate prediction of aerodynamic heating is still a significant technical issue in design process of atmospheric entry vehicles. To validate numerical prediction codes, a large amount of high quality ground test data is vital as a benchmark. However, with too few ground test facilities, the number of ground test reports on aerodynamic heating under high-enthalpy flow conditions, especially high-pressure (i.e. high Reynolds number) flow conditions, is still quite limited. In Japan, we have a free-piston type high-enthalpy shock tunnel HIEST[1] for research on hypersonic real gas flow. HIEST can produce test flow at stagnation pressure up to 150 MPa and at stagnation temperature up to 10000 K. For these extreme flow condition and short test times on the order of ms, measurement technology is still pushing the state of the art. In order to improve the measurement accuracy and precision of the tunnel, a measurement technique enhancement program was therefore launched in FY2008. The final goal of the program is to improve the accuracy and precision of measurements in HIEST to the level of hypersonic blow-down tunnels. Since JAXA has launched Hayabusa-2 project, an aerodynamic heating tests in wind tunnels with capsule configuration has become one of the main research and development themes for us. In the FY2011, an aerodynamic heating test with an Hayabusa 70% scale-model (Fig.1) was performed under high-enthalpy and high-pressure (i.e. high Reynolds number) conditions. The model has thirty-two fast-response coaxial thermocouples on the windward to measure the heat flux distribution. Twelve thermocouples and eight Piezo-resistive pressure transducers were also mounted on the aft of the model and were used to determine flow establishment around the model within short test period. Stagnation enthalpy and stagnation pressure were varied from H_0=3MJ/kg to 22MJ/kg, and from P_0 =14MPa to 50MPa, respectively, which condition was matched to the Hayabusa capsule flight envelope. Under the stagnation condition, the unit Reynolds number was varied from 0.9 million/m to 3 million/m. As shown in the Fig.2, aeroheating distribution was observed at model angle of attack 0 degree with fully laminar boundary layer except H_0=3MJ/kg condition.

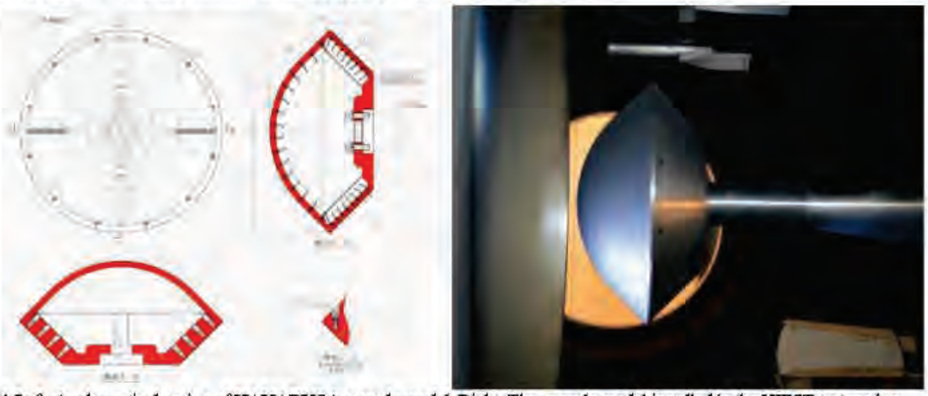

Fig.1 Left: A schematic drawing of HAYABUSA capsule model. Right: The capsule model installed in the HIEST test section.

Session 7A: Airless & Primitive Bodies

M. Fulchignoni : Lesson learned by asteroid exploration missions

Lesson learned by asteroid exploration missions

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Most of information on asteroids comes (and will come for long time) from the ground-based observations, analyzing of the sunlight reflected by these objects. The current scenario of the asteroid population is necessary rough and lack of the details coming from "in situ" observations.

The exploration of asteroids has been developed following a two-folds philosophy: missions of opportunity and dedicated missions.

Concerning the former, during the eighties, meanwhile the Voyagers were completing the fist phase (flyby) of the exploration of the giant planets, the next generation missions were in preparation. In order to exploit at maximum the possibility offered by their trajectories, crossing the asteroid belt, the science advisory bodies of the Space Agencies issued the recommendation that all the mission toward the external regions of the solar system have to schedule as many asteroid fly by as possible in their way toward the final target. Missions Galileo, Cassini-Huygens, Stardust and Rosetta successfully realized a total of six fly-bys of main belt asteroids (including a binary system) on the way toward their main objectives, Jupiter system, Saturn system, the comet Wild 2 and the comet Churimov-Gerasimenko, respectively. The technological mission Deep Space 1, whose main goal was to test the ion drive propulsion of space probes, included as science objective a close fly-by of an asteroid and of a comet.

Up to now, the dedicated missions studied and realized to explore specifically one (or more) asteroid have been NEAR-Shoemaker (one year in orbit around 433 Eros after a fly-by of 253 Mathilde), Hayabusa (sample return from the asteroid 25143 Itokawa) and Dawn (in orbit around 4 Vesta until February 2012, and scheduled to continue its travel toward 1 Ceres and remain one year in orbit around it, starting in 2015).

The conclusion is that in more than 20 years, only thirteen asteroids have been observed with the instruments on board of interplanetary spacecraft. These asteroids exhibit wide differences in size, age, surface texture and composition.

The results of the close-in exploration of this small number of objects will be shortly overviewed, to show how these missions give us the opportunity to know the asteroid nature at a scale order of magnitude higher than the previous one. Moreover, each explored asteroid provides us with some "ground truth" to test the inversion techniques of the data obtained from ground based observations. The next challenge is to get asteroid samples back to the Earth, to complete the tools to have a significant improvement in the understanding of the processes that presided the formation of planets.

The Callisto Descent Probe

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Abstract

The Callisto Descent Probe (CDP) is a small spacecraft originally proposed to be part of the Jupiter Ganymede Orbiter (JGO) of the Europa-Jupiter System Mission (EJSM) of ESA and NASA. After cancelation of the NASA contribution ESA redesigned the mission as Jupiter Icy moons Explorer (JUICE) mission. CDP shall be deployed from the main spacecraft during a dayside Callisto flyby. With the help of a de-orbit engine, the CDP's orbit will be adjusted to intersect the surface of Callisto. Scientific data will be recorded during the decent to the surface. The impact of CDP on the surface will end the science phase of CDP.

The scientific objective of CDP is to provide measurements during the descent phase, thus close to Callisto's surface that will enhance the total scientific return of the Callisto science investigation of JUICE. The areas of investigation of CDP instruments are the composition of neutrals and ions in the atmosphere, visible light imaging, magnetic field investigations, and radio science.

Scientific Instrumentation

Neutral Gas Mass Spectrometer (NMS): to measure the atmospheric neutral gas composition. Much more sensitive mass spectroscopic measurements will be performed during decent than during flyby because the atmospheric density increases dramatically closer to the surface. Moreover, since the atmosphere is in direct contact with the surface it thus provides information of the surface composition.

Ion Mass Spectrometer (IMS): to measure the composition of low-energy ions arriving mainly from Callisto. These ions result from sputtering of ions from the surface from Callisto by energetic particles from Jupiters magnetosphere, and thus also provide information about Callisto's surface composition.

Wide Angle Camera (WAC): for surface imaging in visible light at high cadence to contribute to the characterisation of the surface. In particular, WAC it will provide close up images of Callisto's surface at spatial resolutions of up to 0.25 m/px, which is much better than can be achieved from the JUICE spacecraft.

Magnetometer (MAG): will measure the altitude profile of the induced magnetic field variations generated due to varying Jovian magnetic field induced in Callisto's interior. The actual altitude profile allows drawing conclusions on the strength and structure of the induced field, thus providing information about the inducing layers such as a possible subsurface ocean.

Radio system: allows the reconstruction of the probe's state-vector (coordinates and their time derivatives) by means of VLBI and Doppler measurements.

CDP Design

The CDP is proposed to travel as passenger of the JUICE spacecraft to its final destination Callisto. CDP will be a small spacecraft, its weight is about 50 kg total mass including the separation mechanism. Release of CDP from the JUICE spacecraft and its spin-up will be accomplished with a spring separation system. CDP has a de-orbit engine to change its trajectory to a collision trajectory with Callisto. CDP will also have small thrusters for spin adjustment and stabilisation, as well as attitude control.

Pinpoint Landing Navigation with a Camera: Design and Preliminary Hardware Validation

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Pinpoint landing can significantly improve mission return of robotic planetary exploration. The simplest sensor that can be used for this purpose is an optical camera.

This poster presents a tight visual/inertial fusion scheme based on an Extended Kalman filter to locate the lander vehicle on a map of the planet during the descent. Landmarks are selected at various scales as corners in orbital images of the area. They are matched from orbit to low altitude using reprojected image scale information. This process is robust to rugged terrain topography and illumination changes. Inertial sensors are used to estimate the vehicle motion between two camera frames and define landmark search areas in the image.

A lunar landing test bench was designed and set up at ESA-ESTEC to validate performance with hardware in the loop. A camera is mounted on a robotic arm moving over a planetary mock-up based on NASA-LRO digital elevation models of the Moon. Preliminary results and scaled lunar landing performances are presented.

Lessons learned from the Rosetta fly-by with the asteroid 21 Lutetia

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Rosetta is the cornerstone mission of ESA devoted to the study of minor bodies with the aim to investigate the origin of the Solar System. A launch postponement in 2003 caused the redefinition of the Rosetta orbit and of the mission targets. Rosetta was successfully launched on March 2004 versus the comet 67P/Churyumov-Gerasimenko, that will be reached on 2014. During its journey, Rosetta flew-by two main belt asteroids: 2867 Steins and 21 Lutetia.

The asteroids fly-bys were very successful and Rosetta produced important results on Steins and Lutetia.

Nevertheless, these fly-bys did not allow to solve crucial questions on the structure and some physical properties of the targets. The fly-by with 21 Lutetia, the bigger asteroid (100 km of diameter) seen by a space mission at that time, before the Dawn encounter with Vesta, did not allow to reveal the nature of its surface composition, which was longly debated and still controversial. 21 Lutetia has been extensively studied in the last 30 years, in particular since it was selected as a target of the Rosetta mission. On the basis of the visible colors and moderate albedo values (0.19-0.22) obtained with radiometric measurements, it was classified as a metallic M type asteroid. Nevertheless, its infrared spectrum and the thermal emissivity obtained with the Spitzer space telescope shows a clear analogy to carbonaceous chondrite meteorites.

During the close encounter of the Rosetta spacecraft with (21) Lutetia, the instruments OSIRIS, VIRTIS, ALICE, RSI and MIRO were turned on to characterize the surface properties of the asteroid. The images taken by OSIRIS cameras reveal a complex geology with several pits, craters chains, ridges, and scarps. Lutetia appears to be a very old object with an irregular shape resulting from its collisional history. The spectra acquired by VIRTIS and ALICE are featureless in the 0.5 and 5.0 μ m. The only feature detected is a drop off of the reflectance in the UV range, between 180 and 160 nm, never seen before on asteroid spectra and difficult to interpret due to the lack of laboratory data at these wavelengths. Themal maps by MIRO and VIRTIS reveal a low thermal inertia, consistent with a surface uniformly covered by a fine regolith. The Lutetia density is relatively high (3.4 g/cm^3), similar to that of enstatite chondrite.

Despite the great results obtained from the Rosetta fly-by, several important questions remain unsolved: what is the surface of Lutetia made of? Is the surface fine regolith masking the absorption features of the minerals? Which is the internal structure of the asteroid and the local gravity field? Which is its macro-porosity? Is it a differentiated object?

The Rosetta fly-by with 21 Lutetia underlines the importance to have in-situ examination or, even better, sample return devices. A landing probe or a sampling return mission would have been fundamental to have an extensive analysis of the asteroid surface materials and to solve the puzzle of the Lutetia mineralogy and composition.

DORN/NITON: ALPHA SPECTROMETERS TO STUDY THE TRANSPORT OF VOLATILES ON THE MOON/MARS.

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Introduction: We have been developing an instrument named DORN (Detection of Outgassing RadoN, after the name of the German physicist who discovered this gas) for ESA's Lunar Lander, and another one named NITON (after the first name used for Radon) for Martian atmospheric studies. They both are alpha spectrometers that will work very much like previous Alpha Particle Spectrometer (APS or APXS) that have flown on other planetary missions (Surveyor, MER, Rosetta), but they are dedicated to the measurement of radon and its decay products. Radon is a key tracer of the transport of gases in the lunar and martian environments (regolith and atmosphere/exosphere), which has been targeted by several lunar missions since the early stages of the Moon exploration, but never on Mars. Past measurements revealed time and space variations of its activity at the surface of the Moon, possibly related to the existence of episodic release of volatiles during seismic events or TLPs, through conducts or fracture networks possibly at mare boundaries and young and massive craters [1]. But they have raised more questions than answers, in part because of their limited quality, or limited spatial or temporal coverage.

Objectives: Long-term monitoring of its surface activity, in particular in the South polar region of the Moon, would considerably increase our understanding of its cycle and would enable us to achieve the following objectives: study the transport of gases through the lunar and martian regoliths; monitor the venting activity of the Moon and identify active outgassing spots; study the transport of volatiles in the lunar exosphere and the martian atmosphere; detect an effect of the soil water content on the exhalation rate (direct effect or indirect effect due to its role as a weathering agent); study the transport of lunar and martian dust over time scales of the order of the half-life of ^{210}Pb (~22.3 y); and establish ground truth for orbital measurements of radon, polonium (from Apollo15,16, Lunar Prospector and Kaguya-Selene APS) and uranium (from Kaguya-Selene and Mars Odyssey Gamma Ray Spectrometers), the measurement of the latter being possibly biased by the mobility of radon [2].

Some interesting properties: Radon has many advantages as a tracer. It has a well-identified source term, intrinsic to the regolith: uranium-238, which has been mapped by Kaguya-Selene Gamma Ray Spectrometer [3]. Its only significant loss process is its radioactive decay. The temperature dependence of its adsorption is the strongest of all noble gases, which could lead to a pronounced diurnal cycle, as was observed for argon-40 by Apollo 17 mass spectrometer [4]. It has a limited lifetime (~3.8 days), which is an advantage in the search for active degassing spots. Moreover, it is not subject to chemical contamination issues (radon is necessarily endogeneous). Finally, remote measurements are made possible owing to the infinite range of alpha particles in the lunar exosphere. Therefore, radon appears to be an interesting "benchmark" tracer to study the fragile lunar exosphere before it is polluted by human exploration, and to understand the transport of other volatiles of interest for this exploration.

The instruments: The two instruments are made of two independent subsystems, with different objectives, although their detection unit is identical. The first subsystem is aimed at measuring ^{222}Rn, ^{218}Po, ^{214}Po and ^{210}Po deposited around the lander and originating from a region of radius ~30° in latitude/longitude (for the Moon, approximate distance crossed by radon atoms during their average lifetime of 3.8 days, assuming no reincorporation into the regolith). It is composed of 4 sets of double-sided silicon detectors, measuring alpha particles over the energy range [~1-10MeV] (one side to measure the surface activity, the other one to reject part of the background ionizing radiations). It is ideally located on the edge of the lander, pointing towards different directions (e.g., illuminated and shadowed targets) The second subsystem is designed to measure directly the exhalation rate of radon from the subsurface, at the landing site. It is composed of a microcooler (lunar version only) fixed to a cup layed on the ground, bringing the temperature of a cold finger to ~90K in order to trap escaping atoms by adsorption. Two silicon detectors face this cold finger to measure the activity deposited on it.

References: [1] Crotts, A. P. S (2008), *Astrophys. J.* 687, 692–705. [2] Meslin, P.Y. and Déprez, G. (2012), *43rd LPSC Conference*, Abstract #2800. [3] Yamashita, N. et al. (2010), *GRL*, 37, L10201. [4] Hodges R. R. (1977), *Physics Earth Planet. Sci. Interiors*, 14, 282-288.

VISTA: a thermogravimetry/biosensor system for in-situ analysis of planetary surfaces

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VISTA (Volatile In Situ Thermogravimetry Analyser) is a thermogravimeter-biosensor system developed at INAF (Istituto Nazionale di Astrofisica) in Rome.
Thermogravimetry is a widely used technique to study condensation/sublimation and absorption/desorption processes in the analysed samples. The core of the thermogravimeter is the Piezoelectric Crystal Microbalance (PCM), whose oscillation frequency depends on the mass deposited on it: the higher the mass the lower the frequency. The temperature of the device can be changed by means of an appropriate heater, so that desorption/absorption of different volatile compounds is allowed. The abundance of the released/absorbed volatile compounds is given by the mass variation due to the desorption/adsorption processes, while its composition can be inferred by the desorption temperature.
The MIP (Molecularly Imprinted Polymers) are crosslinked polymers, which are synthesized in the presence of template molecules. The production process uses a target molecule to construct a template of cavities inside the polymer. The cavities so created are then used to trap uniquely (or specifically) the target molecule. The comparison of this technique with others commonly used in the biological analysis field, shows clear advantages of MIP for space mission thanks to its robustness and for the absence of biological contamination risks of extraterrestrial environments.
If coupled with a drilling/soil sample selection device, VISTA can be suitable for an in-situ mission to an asteroid or a satellite, thanks to its low mass (25g) and the low required power (in vacuum, only 50 mW occur to obtain a temperature increase of 60°C).
VISTA is under study for the Phase A of the proposed ESA Cosmic Vision mission MarcoPolo-R, addressed to a primitive asteroid, and JUICE. In the second case, it should be coupled with a Penetrator, designed for the surfaces of Europa and Ganimede.
In the MarcoPolo-R scenario, VISTA will have the following scientific purposes: a) to detect the possible cometary activity of the asteroids; b) to aid in determining the taxonomy of the asteroid regolith. The first purpose can be reached setting up the PCM to a low temperature in order to allow the condensation of gases ejected by the possible cometary activity. For the second purpose, the PCM should be heated up to temperatures where organic and water desorptions occur (200-500 °C), so that the measurement of their abundance in the asteroid regolith (related to its taxonomy) would be allowed.
In the JUICE scenario, the aims are to: a) discern water ice and clathrate hydrates (which have different sublimation temperatures); b) infer the composition of non-ice materials on the satellite surfaces; c) detect the possible presence of organic molecules. The last two purposes will be likely reached combining thermogravimetry and MIP techniques.
In this presentation, the VISTA calibration operations (such as the frequency vs temperature and power vs temperature curves) and the first thermogravimetry experiments will be described.

Thermal Design of a Lunar Penetrator

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The thermal design of a lunar penetrator intended to operate for a minimum of two weeks in polar cold traps is analysed and discussed. Local temperatures in polar cold traps can reach 35 K. The aim of this study is to assess whether it is possible to design the thermal control subsystem of the penetrator to achieve its target lifespan of one year without resorting to the use of Radioisotope Heating Units or other nuclear devices. Various different designs and materials are assessed, with mass and ability to survive 15000g impact as criteria. The designs are assessed using heat transfer principles with results being confirmed with ESATAN Thermal Modelling Suite. Factors such as mass of the subsystem, power requirements and complexity were taken into account. The final design incorporates elements to reduce both conductive and radiative heat loss. With the proposed design, the lifespan can be increased from seconds to days. Incorporating a phase change material heat storage system and further design features based on shape memory alloys, the payload can be kept operational for over two weeks. As yet, no practical method of extending the lifespan of the penetrator to a year has been found.

Next Gen NEAR: Near Earth Asteroid Human Robotic Precursor Mission Concept

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Asteroids have long held the attention of the planetary science community. In particular, asteroids that evolve into orbits near that of Earth, called near-Earth objects (NEO), are of high interest as potential targets for exploration due to the relative ease (in terms of delta V) to reach them. NASA's Flexible Path calls for missions and experiments to be conducted as intermediate steps towards the eventual goal of human exploration of Mars; piloted missions to NEOs are such example. A human NEO mission is a valuable exploratory step beyond the Earth-Moon system enhancing capabilities that surpass our current experience, while also developing infrastructure for future mars exploration capabilities. To prepare for a human rendezvous with an NEO, NASA is interested in pursuing a responsible program of robotic NEO precursor missions. Next Gen NEAR is such a mission, building on the NEAR Shoemaker mission experience at the JHU/APL Space Department, to provide an affordable, low risk solution with quick data return. Next Gen NEAR proposes to make measurements needed for human exploration to asteroids: to demonstrate proximity operations, to quantify hazards for human exploration and to characterize an environment at a near-Earth asteroid representative of those that may be future human destinations.

The Johns Hopkins University Applied Physics Laboratory has demonstrated exploration-driven mission feasibility by developing a versatile spacecraft design concept using conventional technologies that satisfies a set of science, exploration and mission objectives defined by a concept development team in the summer of 2010. We will describe the mission concept and spacecraft architecture in detail. Configuration options were compared with the mission goals and objectives in order to select the spacecraft design concept that provides the lowest cost, lowest implementation risk, simplest operation and the most benefit for the mission implementation.

The Next Gen NEAR spacecraft was designed to support rendezvous with a range of candidate asteroid targets and could easily be launched with one of several NASA launch vehicles. The Falcon 9 launch vehicle supports a Next Gen NEAR launch to target many near-Earth asteroids under consideration that could be reached with a C3 of 18 km^2/sec^2 or less, and the Atlas V-401 provides added capability supporting launch to NEAs that require more lift capacity while at the same time providing such excess lift capability that another payload of opportunity could be launch in conjunction with Next Gen NEAR.

Next Gen NEAR will measure and interact with the target surface in ways never undertaken at an asteroid, and will prepare for first human precursor mission by demonstrating exploration science operations at an accessible NEO. This flexible mission and spacecraft design concept supports target selection based on upcoming Earth-based observations and also provides opportunities for co-manifest & international partnerships. JHU/APL has demonstrated low cost, low risk, high impact missions and this mission will help to prepare NASA for human NEO exploration by combining the best of NASA's human and robotic exploration capabilities.

A miniaturised laser-ablation mass spectrometer for in-situ chemical analysis of planetary solids

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Abstract

Laser ablation/ionisation mass spectrometry (LIMS) has been recently adopted for space research. A miniaturised laser ablation mass analyser (LAZMA) was part of a payload on Phobos-Grunt mission and is selected also for the missions to the Moon, Luna-Resurs and Luna-Glob. The LAZMA instrument combines a laser ablation/ionisation ion source with a miniaturised time-of-flight mass analyser. It will be used to study the chemical composition of solid materials, regolith and rocks. (Managadze et al., 2010; Wurz et al., 2012)

We have developed a similar laser ablation mass analyser (LMS) in Bern, which differs slightly in principles of ion detection. The instrument was designed initially for a lander on BEPICOLOMBO mission. The space instrument would have a cylindrical shape with a length of 120 mm and a diameter of 60 mm. Its weight at in situ application will be of about 1.5 kg (all electronics included) and will require 3 W for operation. (Rohner, 2003) Initial studies with a IR laser radiation for ablation, atomisation and ionisation of solid materials indicated a high instrumental performance in terms of sensitivity and mass resolution (Tulej et al., 2011) yielding detection of trace elements down to sub-ppm levels. Recently significant improvements of the performance to that reported have been made after several modifications to the detection and acquisition system and the introduction a computer controlled performance optimiser. (Bieler et al. 2011) The current performance studies with a UV laser radiation show that the instrument can support relatively high resolution investigation ($m/\Delta m \approx 1000$) with an effective dynamic range exceeding 10^8. A computer-controlled optimiser controls the reproducibility of the performance of the mass analyzer, the laser fluence and the positioning of the sample. The system supports highly sensitive studies of elemental composition with sub-ppm detection limits for metallic and non-metallic elements. Our initial studies of lead isotopic composition indicate an accuracy and precision in the per mile range, which are comparable to that achieved by other - well known in isotopic analysis - mass spectrometric techniques, i.e., TIMS, SIMS, LA-ICP-MS. The instrument has the potential for highly sensitive in situ measurements of trace elements with the detection limits down to dozens of ppb and can be useful for investigation of isotope fractionation effects (e.g. age dating, isotopic biomarkers).

References

1) G.G. Managadze, P. Wurz, R. Z. Sagdeev, A.E. Chumikov, M. Tuley, M. Yakovleva, N. G. Managadze, A. L. Bondarenko, 2010, "Study of main geochemical characteristics of Phobo's regolith using laser time-of-flight mass spectrometry, " Sol. Sys. Res. **44**, 376-384.

2) P. Wurz, D. Abplanalp, M. Tulej, M. Iakovleva, V.A. Fernandes, A. Chumikov, and G. Managadze, 2012, "In Situ Mass Spectrometric Analysis in Planetary Science," Sol. Sys. Res., in press.

2) M. Tulej, M. Iakovleva, I. Leya, and P. Wurz, 2011, „A miniature mass analyser for in situ elemental analysis of planetary material: performance studies," Analytical and Bioanalytical Chemistry, **399**, 2185.

3) U. Rohner, J. Whitby, and P. Wurz, 2003, „A miniature laser ablation time-of-flight mass spectrometer for in situ planetary exploration," Meas. Sci. Technol., **14**, 2164.

DEVELOPMENT AND TESTING OF AN INTEGRATED NAVIGATION SENSOR FOR PLANETARY HOPPER NAVIGATION

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ABSTRACT

In recent years, considerable attention has been paid to planetary hoppers for their potential to overcome the limitations on landing precision and mobility facing current planetary surface exploration technologies. This paper describes the development of a unified vision and inertial navigation system for propulsive planetary hoppers and provides demonstration of this technology. A sensor testbed, including a stereo vision package and inertial measurement unit, was developed to act as a proof-of-concept for this navigation system architecture. The system is shown to be capable of outputting an accurate navigation state estimate for motions and trajectories similar to those of planetary hoppers.

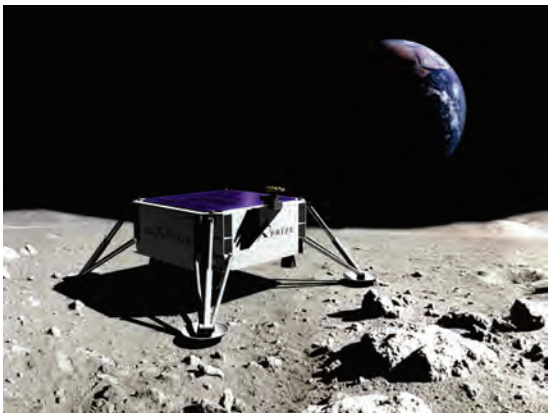

Fig. 1: A conceptual hopper designed for use on the moon. Image credit: Draper Laboratory/Next Giant Leap

1. INTRODUCTION

Planetary hoppers are vehicles that traverse planetary surfaces using chemical exhaust propulsion alone, freeing them from many of the limitations of rovers and stationary landers. This allows hoppers to fine-tune their landing sites to very high levels of precision, while also allowing exploration of a wide range of otherwise inaccessible terrain. For this reason, analogies such as "reusable landers" and "airless helicopters" are sometimes used to describe the unique mission profiles they enable.

Hopping vehicles provide advantages over traditional surface exploration vehicles, such as wheeled rovers, by enabling in-situ measurements in otherwise inaccessible terrain [1]. However, significant development over previously demonstrated vehicle navigation technologies is required to accomodate the additional, unique motions of hoppers that must be accounted for beyond those typical of conventional planetary landing and surface navigation systems [2]. An example of a conceptual hopper is shown in Fig. 1.

Hopping requires a fully autonomous, internal navigation system capable of handling rapid, near-surface motions in an unknown environment. Autonomy is required due to the long communication delays to the Moon or other planets, which eliminate the possibility of remote operation due to the rapidity of hopper motions. The system must be entirely internal and self-contained because installing a large-scale external navigation system (e.g., a GPS-like system) on another planetary body is prohibitively expensive. The system must be capable of navigating in an unknown environment, as a hopper might be called upon to explore areas unavailable from orbital imagery, such as permanently shadowed craters or underneath overhangs of cliffs [3].

The navigation systems developed for traditional exploration vehicles cannot meet these needs. Navigation systems onboard prototype hoppers currently in development for testing on Earth are typically dependent on either an external system, such as GPS [4], or prior knowledge of their environment [5]. Terminal-descent and landing navigation systems, such as [6–9], are not designed for extensive near-surface operation or high-rate translational motion. Helicopter navigation systems, such as [10–13], are capable of handling translational motion, but are generally dependent on GPS or other external systems, such as a barometric altimeter or remote operator.

Power and Thermal design for Ganymede and Europa Penetrators

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The Europa Jupiter System Mission (EJSM) is a proposed NASA-ESA mission to the Jupiter system. The mission is composed of two orbiters, the NASA operated Jupiter Europa Orbiter (JEO), and the ESA operated Jupiter Ganymede Orbiter (JGO). It has been suggested that it would be beneficial to the science of the mission to include penetrators to impact these moons. In order to maximize the scientific data collected, it is necessary to optimise the power and thermal design of these penetrators. The aim was to enable a penetrator to last 2 weeks on Ganymede and 1 year on Europa.

For Europa, many different power sources were considered and a Radioisotope Thermoelectric Generator (RTG) was selected, due to the surface conditions. RTG's are usually mounted away from spacecraft on booms, so the thermal design for an RTG mounted inside the steel shell of a penetrator was extremely challenging. An innovative design was developed which enabled the penetrator to survive hot and cold cases. The design of the structure was constrained by the need for the penetrator to survive the 15,000g impact into the surface of Europa (which was assumed to be water-ice for the sake of calculations). The design was modelled using thermal modeling software ESATAN-TMS and verified using hand calculations derived from first principles. Figure 1 shows the thermal balance over a year derived from ESATAN-TMS results.

For Ganymede, as ESA is responsible for this part of the mission, an RTG was not considered and advanced primary batteries were chosen as the power source. The limitations this imposed on the power budget meant that a passive thermal system was the only option. A vacuum flask design was used, involving detailed design of struts and shock absorbers. This allowed the penetrator to survive impact and the hostile thermal conditions of Ganymede's surface. Figure 2 shows that the final design will survive the two week target lifetime, using only the heat dissipation from the internal electronics as a heat source.

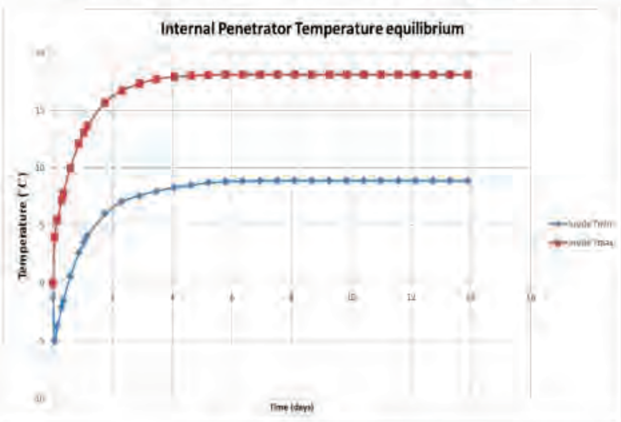

Figure 1: Equilibrium demonstrates survival for 1 year

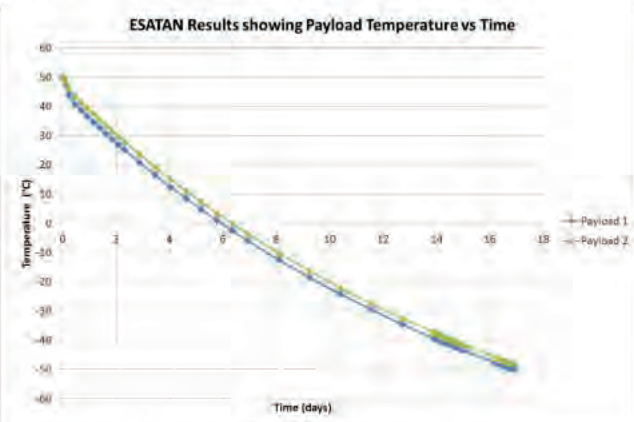

Figure 2: Survival on Ganymede for 2 weeks

NASA's Robotic Lunar Lander Development Program

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Over the last five years, NASA has invested in development and risk-reduction for a new generation of planetary landers capable of carrying instruments and technology projects to the lunar surface and other airless bodies. The Robotic Lunar Lander Development Program (RLLDP) is jointly implemented by NASA Marshall Space Flight Center (MSFC) and the Johns Hopkins University Applied Physics Laboratory (APL). The RLLDP team has produced mission architecture designs for multiple airless body missions to meet both science and human precursor mission needs. The mission architecture concept studies encompass small, medium, and large landers, with payloads from a few tens of kilograms to over 1000 kilograms, to the Moon and other airless bodies. To mature these concepts, the project has made significant investments in technology risk reduction in focused subsytems. In addition, many lander technologies and algorithms have been tested and demonstrated in an integrated systems environment using free-flying test articles. These design and testing investments have signifcantly reduced development risk for airless body landers, thereby reducing overall risk and associated costs for future missions.

Lunar Dust Environment and Plasma Package for Lunar Lander – Definition Study

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Dust, the charged lunar surface, and the ambient plasma form a closely coupled system. The lunar surface is permanently under the influence of charging effects such as UV radiation or energetic solar wind and magnetospheric particles. The surface charging effects result in strong local electric fields which in turn may lead to mobilization and transport of charged dust particles. Furthermore, the environment can become even more complex in the presence of local crustal magnetic anomalies or due to sunlight/shadow transitions. A detail understanding of these phenomena and their dependence on external influences is a key point for future robotic and human lunar exploration and requires an appropriately tuned instrumentation for in-situ measurements.

Here we present preliminary results from the concept and design phase A - a study of the Lunar Dust Environment and Plasma Package (L-DEPP, see Figure 1), which has been proposed as one of model instrument payloads for the planned Lunar Lander mission of the European Space Agency. Focus is held on scientific objectives and return of the mission with respect to environmental and mission technology constraints and requirements. L-DEPP is proposed to consist of the following instruments: ELDA - Electrostatic Lunar Dust Analyser, LP - Langmuir Probe, RADIO - Broadband radio receiver and electric field antennae, LEIA - Lunar Electron and Ion Analyser, and MAG - Fluxgate magnetometer. In addition to the dust and plasma measurements the RADIO experiment will provide a site survey testing for future radio astronomy observations.

Figure 1: Lunar Dust Environment and Plasma Package

ILMA: Ion Laser Mass Analyser. A High-Resolution Mass-Spectrometer for In-Situ Characterization of a Near Earth Asteroid (NEA)

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Asteroids belong to the class of small solar system bodies that are remnants of planet formation. They are valuable objects to assess the physicochemical conditions prevailing at the time and place of their formation in the Solar Nebula. The M3 mission MarcoPolo-R studied by ESA, is a sample return mission to a primitive Near-Earth Asteroid (NEA). MarcoPolo-R will return bulk samples (up to 2 kg) from an organic-rich binary asteroid to Earth for laboratory analyses.

But even in the frame of a sample return mission, a meticulous *in situ* analysis of the target of the Marco Polo-R mission is necessary to provide a field measurement in their actual space conditions, before the samples are stored and brought to Earth after a long journey in a space capsule. Some of the most pristine organic material, suspected to be in carbonaceous primitive small bodies, can be very sensitive to temperature and be altered during transportation. Outgassing can also be an issue. Spectral confusion being a real issue for high molecular weight organic compounds with optical instrumentation, only high resolution mass spectrometry can provide in depth and instantaneous analysis of the samples, including molecular structure of complex organic molecules.

ILMA is a concept for a new generation high resolution mass spectrometer. It is being studied as a potential Marco Polo-R payload instrument, for *in situ* measurements from both an orbiter and a lander. The instrument concept is based on Laser Desorption and Ionization Mass Spectrometry (LDIMS). The innovative part of the instrument is a Fourier Transform ion trap mass spectrometer, which is based on the Orbitrap mass analyzer.The sample exposed to the laser beam produces sputtered ions which are collected into the ion trap using the orbital trapping method. Ions are stabilized in the trap by purely electrostatic quadro-logarithmic electrical fields and the detection undertaken by a non destructive measurement of the ion oscillation frequency inside the trap. Indeed, the trapped ions induce a periodic signal converted using Fourier Transform (FT) into an ultra-high mass resolution spectrum ($M/\Delta M > 60{,}000$ up to $m/z = 400$ u). The goal of the on-going study is to develop a high-performance, low-resource (mass< 5 kg, power < 10 W, volume < 5 L) mass spectrometer for space applications. ILMA is intended to represent a major step compared to previous mass spectrometers in space. It would have the capability to distinguish isomass compounds and measuring *isotopomer* abundances.

ILMA is being designed to be able to measure *in situ* chemical (mineral and organic) and isotopic composition of the NEA surface material. The ILMA team goal is to develop an instrument that will allow addressing with unprecedented capability the key question of the astrobiological relevance of NEAs for the study of the origin of life on Earth.

IPPW-9 Dusty plasma near Moon surface.

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Recently we have the some reemergence for interest of Moon investigation. The prospects in current century declare USA, China, India, and European Union. In Russia also prepare two missions: Luna-Glob and Luna-Resource (together with India). Not last part of investigation of Moon surface is reviewing the dust condition near the ground of landers. Polar area setdown descent modules supposed low sunniness however lifting of dust particle anyhow is possible.

On light side of Moon near surface layer there exists possibility formation dusty plasma system. Altitude of levitation is depending from size of dust particle and Moon latitude. Silent zone formation of levitation near 80 N/S latitude is absent because of shield effect bound-free absorption with influence photoelectron. The distribution dust particle by size and altitude has estimated with taking into account photoelectrons, electrons and ions of solar wind, solar emission.

Session 7B: Cross-Cutting Technologies II

S. Cornelli (Student) : SIMION Simulations of a new Orbitrap Spectrometer Prototype for Space Application

SIMION simulations of a new Orbitrap Mass Spectrometer Prototype for Space Application

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A new concept of mass analyser for space applications that is lightweight, uses pulsed DC voltages and provides ultrahigh resolving power capabilities (M/ΔM beyond 100 000 up to *m/z* 400) is now studied for a use in future space missions: the Orbitrap.

The Orbitrap mass spectrometer technology was successfully applied in many fields of research since its proof of concept in 2000 (1). It employs the trapping of pulsed ion beams in an electrostatic quadro-logarithmic field created between 2 barrel-shaped electrodes. Stable ion trajectories combine rotation around the central electrode with harmonic oscillations along it. These oscillations are detected using image current detection and are transformed into mass spectra using Fourier Transform. The lightweight, the absence of magnetic device and the very high resolution and good sensitivity of this mass spectrometer make it very attractive for space exploration.

Since 2009 CNES has funded a R&T program in order to study a space version of the Orbitrap concept. In 2010, a proposal for a dust analyser in the vicinity of Jupiter, including the Orbitrap analyser as optional payload, has been recommended by ESA for a study in the frame of the EJSM (now JUICE) Cosmic Vision mission (2). A consortium of laboratories located in France, LATMOS, LPC2E, LISA, coordinate by IPAG in collaboration with Thermoelectron company was organized and a first prototype is now running at LPC2E, Orléans.

A new version of the prototype, closer to space environment applications will be developed and tested at IPAG-Grenoble. The poster will present the results of ion trajectory (SIMION) simulation activities, developed in IPAG in order to simulate and study by means of Monte Carlo methods the important step of ion injection in the Orbitrap analyser. By the use of these simulations, we can study various concepts of electrode geometry and shapes and timings before undertaking the prototype mechanical realization.

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(1) A. Makarov, "Electrostatic Axially Harmonic Orbital Trapping: A High-Performance Technique of Mass Analysis", Anal. Chem., (2000) 72, 1156-1162.
(2) S. Kempf et al. "linear high resolution dust mass spectrometer for a mission to the Galilean satellites" Planetary and Space Science in press DOI: 10.1016/j.pss.2011.12.019

LIDAR TECHNOLOGIES FOR AEROSOL PROFILING IN PLANETARY ATMOSPHERES

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An assessment of the aerosol abundance and distribution in planetary atmospheres is mandatory for an accurate retrieval of both atmosphere chemical compositions and surface characterization.The LIDAR (Light Detection And Ranging) technique allows for a determination and characterization of aerosol profiles. This technique allows for profiling a semi-transparent medium as long as its optical depth is of the order of some unity. In such cases, elastic multi-wavelength LIDARs are apted to describe suspended particles, permitting an estimation of the aerosol size, and to deliver information on particle shapesby means of the polarization diversity techniques. Airborne and spaceborne LIDARs, or automated ground-based instrument deployed in heavy duty conditions (deserts, poles), have been used since a long time for a description of the aerosol content of the terrestrial atmosphere and the technology is now mature enough for planning the deployment of such instruments in an extra-terrestrial mission. In fact, the current technology has allowed mission in the terrestrial stratosphere, with long duration balloons and stratospheric aircraft, as well as on spacecraft and satellites on polar orbit. So, such instruments would be in principle usable wherever environmental conditions, as pressure, temperature and adverse chemical conditions, would allow. As instance, a light-weight and low power instrument with dual wavelength and polarization diversity capability would be a perfect candidate for exploring the aerosol content of several planets and satellites atmospheres, namely the terrestrial planets as Mars and Venus, but also outer planets or moons like Jupiter, Saturn and Titan. Depending on the specific target, the instrument could be deployed on small orbiting platforms, on balloons drifting in the atmosphere, on parachute and even from grounds, allowing the remote sensing of aerosol for a range of several chilometers.

A survey of current capabilities of LIDAR systems and an outlook toward their usage in sounding planetary atmosphere will be here presented, with special emphasis on possible advantages and drawbacks of specific planetary environments.

Frequencies Consideration for Surface Communications in the Lunar Region

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This paper aims to consider the Mobile Satellite Service (MSS) downlink S-Band [2483.5 – 2500] MHz, and the MSS uplink L-Band [1610 – 1626.5] MHz as suitable in the Lunar vicinity, for Orbit to Surface and Surface to Orbit communications.

This MSS downlink frequency band is already used for Space-to-Earth link to provide Mobile communication Satellite Services, and was recently allocated at WRC-12 to the whole part of the world for the Radionavigation & Radio Determination Satellite Services (RDSS). Thus, this world allocation on the same frequency bandwidth for MSS and RDSS should create, in short and middle term frames, interesting synergies between communication and radionavigation applications, and produces technologies and services evolvement.

Moreover, the proximity of this MSS S-Band to the Industrial, Scientific, and Medical [2400 – 2483.5] MHz adjacent band, which is already considered by some space agencies to provide short surface low power proximity links on the Lunar surface, can be considered as another potential synergy to increase applications on similar User Terminal (UT).

Using the [2483.5 – 2500] MHz on the forward link (Orbiter-to-UT) should allow hybridisation between direct line-of-sight and relay communication links, both combining localisation and navigation functions.

This concept for Lunar surface links is totally suitable, in terms of use, to the mission profiles which are already identified into international technical working groups (CCSDS SLS-PlaCom, SFCG-LMSG, or NASA-ILN). Thus, it can be possible to consider a MSS system which provide medium data rate communication links for robotic exploration systems (rovers, seismological autonomous sensors,) or even for manned missions at the lunar surface (Voice, TT&C, Comm & Nav Data).

This paper presents a technical study on interference risk assessment between two considered MSS systems, one in the Moon vicinity, and the other in the Earth vicinity. For practical reason, the Globalstar waveform working on MSS frequency band is considered as example to calculate interference risk assessment from any potential MSS system in the lunar vicinity.

A system like the current Globalstar, despite its low data rate performance comparing to the last communication technologies for proximity links (OFDM WiMax,), could offer reliable emergency proximity links for lunar manned missions needs. Moreover, next generation of terrestrial MSS systems should evolve toward these last communication (and navigation) technologies, and increased data rates.

Planetary Radio Interferometry and Doppler Experiment for Near-Earth Asteroids ESA mission MarcoPolo-R

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The core of the Planetary Radio Interferometry and Doppler Experiment (PRIDE) is the accurate estimation of the state-vector of a spacecraft using Very Long Baseline Interferometry (VLBI) tracking. In this contribution, we will describe the technique and the technical requirements as well as the multidisciplinary scientific outcome of PRIDE as a part of the ESA mission MarcoPolo-R towards the Near-Earth Asteroids.

The Planetary Radio Interferometry and Doppler Experiment for the MarcoPolo-R ESA mission will address the following scientific areas:

- Ultra-precise celestial mechanics of a binary Near-Earth Asteroid system;
- Geodynamics, internal structure and composition of primordial asteroids;
- Shape and gravimetry of the asteroids.

These are key points for studying the physical properties and the evolution of potential building blocks of terrestrial planets.

Due to the ability to provide precise measurements of spacecraft lateral coordinates, radial velocity and its derivatives, PRIDE will contribute into estimates of the mass and gravity field of MarcoPolo-R study objects. Furthermore tracking the orbiter in the gravity field of binary Near-Earth Asteroid will allow us not only to determine the spacecraft trajectory but also to improve the ephemerides of the Near-Earth Asteroids. VLBI tracking of the orbiters in combination with routine observations of radio sources of the celestial reference frame will allow us to firmly tie the binary asteroid system into the reference frame. This would represent a major contribution to Near-Earth planetary geodesy and the definition of the Solar System reference system.

High Resolution Orbitrap Mass Spectrometer for In-Situ Analysis in Planetary Science: Prototype results.

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Solar System exploration is dealing more and more with chemically complex matter, potentially associated with astrobiology or prebiotic questions.Due to its ability to reveal quantitatively almost any chemical element, mass spectrometry has served as an invaluable scientific analytical instruments. Nevertheless the best mass resolution($m/\Delta m$) currently achieved by mass spectrometers in space is about 3000 at mass 28 (ROSINA's DFMS on board ESA's comet chaser Rosetta). This resolution allows separation of peaks for only a limited number of isobaric species (e.g. N_2 / CO at 28 Da). A significant breakthrough in flight instrumentation performance is required to address the current big science questions. As mass-resolving power increases, several new plateaus of chemical information become accessible. FT MS offers (i) the multiple advantages of yielding the entire mass spectrum at once, rather than requiring that each peak be scanned through separately and (ii) in the zero-collision limit, mass-resolving power increases directly with data acquisition period. In 2000, a new concept not requiring any magnetic or RF fields was demonstrated to be feasible for FT MS: orbitrap [1, 2]. Purely electrostatic orbital traps in laboratory are showing mass resolution above 100 000 for m/z <= 400, that provides separation for each detected isobaric species. Moreover this concept is extremely small.

Our French consortium of laboratories, in collaboration with ThermoFischer Scientific, is currently working on the adaptation of this type of mass spectrometer for space instrumentation. We are also in the process of preparing for a stratospheric balloon flight to raise our instrument's TRL. A laboratory prototype has been developed as the first step of our space instrument development plan.

We present here this innovative concept of mass analyzer for space that is lightweight, uses DC voltages, and provides ultra high resolving power capabilities. The performances of our laboratory prototype are presented. A mass resolution of 140,000 at mass 56 has been recently achieved. The new exciting opportunities for molecular characterization, isotopic abundance evaluation, and more generally environmental characterization are briefly discussed.

References: [1] MAKAROV, A., "Electrostatic Axially Harmonic Orbital Trapping: A High-Performance Technique of Mass Analysis", Anal. Chem., 72, 1156-1162 (2000), [2] HU, Q. et al. "The Orbitrap: a new mass spectrometer", J. Mass Spectrom. 40, 430–443 (2005)

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Development of Smaller Power Technologies For Use in Planetary Probes

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Power conversion is essential to any circuit on board a planetary probe. The University of Idaho Integrated Passives Research Team has been developing high voltage performance power converters on chip in low voltage fabrication processes to improve power conversion. The Integrated Passives team creates the chips and power circuits, whereas Dr. Choi of the Materials Science Department at UI along with Dr. Hong has created the inductors and capacitors that are post processed on the chip using nanoscale fabrication methods. This results in the creation of more improved power converters on chip. These power converters are able to interface lightly regulated, high voltage DC inputs into regulated DC outputs for use on chip. The chips are designed with both bulk CMOS and Silicon on Insulator (SOI), radiation hardened and not. Those power converters that are designed with SOI radiation hardened processes are given a clear advantage over bulk CMOS circuits. The SOI process creates better voltage isolation which in turn improves high voltage performance, bandwidth and temperature characteristics and also gives better temperature and radiation performance than similar bulk CMOS circuitry. They are readily laid out and can handle about ten times the input voltage rating of the process. The results of this research are more efficient power supplies that are smaller, lighter and closer to the load. These supplies are almost always contained within the same package and in many cases placed on the same chip, saving space and allowing for more components in the circuit. This work has significant advantages for planetary probes which must either be contained within a tightly spaced environmentally controlled area or, in some cases such as SOI versions, they can survive more radiation and temperature extremes.

Enhancing Planetary Wind Measurements with Radio Science Flight Instruments

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Advances in Radio Science flight instrument technologies and post-processing capabilities allow for the possibility of utilizing a One-Way sequential ranging signal transmitted from Deep Space Network antennas and recorded onboard a probe-mounted Radio Science open-loop receiver with onboard post-processing algorithms to produce precision measurements of probe range and position, thereby significantly improving atmospheric wind retrievals using standard probe-orbiter Doppler Wind retrieval techniques. The probe velocity relative to Earth is computed as the derivative of the ranging positional information and is therefore unaffected by any constant biases in the ranging data. In addition, velocity derived from ranging data will not have an error term that grows with the descent time. By providing an accurate Earth-to-probe baseline range and velocity, knowledge of the planet-centered probe descent location can be significantly improved. Additionally, probe measurement of the DSN uplink signal can provide a second projection of the horizontal winds that, when coupled with the probe-orbiter wind projection, will provide the complete horizontal wind vector. To make the measurements fully complementary, the angle between the Earth-to-probe and probe-to-orbiter baselines should be large, and to increase the sensitivity to winds in the probe local horizontal plane, the probe-orbiter and probe-Earth angles should be at a non-zero angle to the probe nadir vector.

In this paper we will review opportunities for and benefits of using a Radio Science Instrument "Open-Loop Receiver" to improve the accuracy of planetary atmospheric wind profiles measured during entry probe descent.

Printed Microstrip Antennas Designed for Small Spacecraft at Ultra High Frequencies

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The cost for putting instruments into space grows immensely as the size and weight of a spacecraft increases. This constraint has urged NASA to pursue technology that will enable smaller, cost efficient spacecraft. Antennas are required for spacecraft communication, tracking, and radioscience and size is often a limiting factor. At low frequencies, the size of antennas can become significant. Microstrip antennas are relatively inexpensive to design and fabricate and are desirable at Ultra High Frequencies (UHF) due to the properties of the antenna that are directly tied to the wavelength at the resonant frequency. Microstrip antennas are electrically small (small relative to a wavelength) and therefore are ideal for use on very small satellites (CubeSat, PicoSat, and NanoSat). We are investigating the properties of electrically small UHF antennas for use on small spacecraft. Technologies that are currently being used for antenna design in various applications will be evaluated and compared. These designs will then be adapted and optimized for small spacecraft environments.

In-situ Strain and Deformation Measurements of Inflatable Aeroshell Test Articles

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Hypersonic Inflatable Aerodynamic Decelerators (HIADs) expand the options for payloads entering atmospheres of planetary bodies by greatly lowering ballistic coefficient of an entry vehicle. As part of a broad technology maturation plan, National Full-Scale Aerodynamics Complex (NFAC) wind tunnel testing is planned to develop design, analysis, manufacturing, and assembly techniques for inflatable aeroshell structures. The testing will aid in the validation of finite element analysis techniques used to predict deformations and stress fields of inflatable aeroshell structures under aerodynamic loading. The difficulty of predicting the fabric response in an aerodynamic environment is increased by the complexity of the HIAD model design. Secondary objectives for the NFAC testing include, but are not limited to, measuring hysteresis of HIAD deformation and the evaluation of developmental instrumentation. To this end, strain gauges are considered for possible in-situ strain measurements of the HIAD structural and toroid straps. Traditional strain sensors are not compatable with the large deformations of textile fabrics. Elastomeric strain sensors constructed from Conductive Polymer Composites (CPC) can potentially overcome this limitation by combining the high electrical conductivity of metal with the low modulus of elastomers. As these sensors are not an established technology, an investigation of their feasibility and applicability was undertaken. This work presents results from uniaxial tension testing of the HIAD straps. The goal of the tensile testing was to acquire data for characterizing the CPC sensor's behavior in a simulated loading environment. Specifically, the hysteresis and relaxation behavior of the Kevlar straps alone were observed and compared to that of the straps with the sensors applied. In addition, this effort sought to determine the feasibility of utilizing these sensors for in-situ measurements. The complex strap configuration for the HIAD model is shown on the left of Figure 1, while the proposed sensor layout is shown on the right.

Figure 1: (Left) HIAD Developmental Model and (Right) Proposed Sensor Layout

Nano-Composite Materials for the Construction of Space Probes – An Investigation on Fracture Toughness of Hybrid Interfaces

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The utility of composite materials is increasing due to their outstanding performance such as lightweight and ability to sustain high mechanical loadings in extreme environments, for example in high temperature and pressure conditions. As a result, they are highly considerable in the design of aerospace vehicles. In particular, the Boeing 787 Dreamliner aircraft was built with mostly composite materials, for instance, on its fuselage, wings, tail, doors, and interior. This aircraft has shown a substantial reduction in fuel consumption compared to other aircraft designs of the same size due to the decrease in mass. Thus, composite materials are great candidates for the construction of space probes. For example, they can be used to construct the shell underneath the thermal-protecting system (TPS) of the probes or the orbiter and lander in aerocapture spacecraft to sustain mechanical loads. Good mechanical properties as well as adhesion to the TPS layer are of high significance in the design and selection of composite materials.

The motivation for this study is to create robust polymer matrix composites that can sustain thermo-mechanical loads given the entry of probes into different planetary atmospheres; and facilitate joining techniques for the composite to the TPS. Composite laminates that contains carbon fabrics, carbon nanotubes (CNTs), epoxy matrix and Titanium foil were designed and fabricated. The CNTs grown on the fabric surfaces create the fuzziness – the fabric or interface with CNTs on its surface are called fuzzy fabric or fuzzy interface. Fracture toughness is one of the most important mechanical properties of a material. It represents the ability of that material to resist fracture when an initial crack is presented in that material. This is especially important in composite materials because they consist of multiple constituents; thus, initial cracks are introduced and propagated during manufacturing and performing under different environments and over periods of time. In this work, the fracture toughness of fuzzy interfaces is investigated as a function of temperature, by both experiments and modeling. Typical mode I fracture toughness tests, the double cantilever beam (DCB) experiments, are performed at both room and elevated temperature, 110°C. Compared to the laminate where CNTs do not exist at the interface, fuzzy interface shows improvement in fracture toughness up to 2.5 times. Modeling work using the finite element method is carried out to simulate the experiments and help explain the damage modes observed. Two and three-dimensional models are created and analyzed in a commercialized finite element software such as ABAQUS using the virtual crack closure technique (VCCT). Results for fracture toughness from both experiments and models will be compared.

The benefits of using composite materials to construct space probes include substantial reduction in mass of the probes while performing much better under extreme environments during entry into planetary atmospheres, and heavy loading conditions during launch and landing. Consider just the probe aeroshell, the entry of a probe into a planetary atmosphere experiences high temperature and pressure gradients; thus, the shell layers are subjected to different thermal and mechanical stress fields. This causes the shell materials to deform and fracture gradually, and the TPS is easily to debond from the structure underneath it. This study proposed a system of composite materials that has high resistance to fracture to build the parts of probes that carry heavy mechanical loads. The problem about adhesion and debonding between the TPS and composite shell layers was also addressed here with the study on bimaterial interface between Titanium and composite. To sum up, it is worthwhile to consider composite materials in the design of future planetary probe missions.

NASA Thermal Performance Data System

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A Thermal Performance Data System (TPDS) was developed to manage thermal performance test results generated in arc jet tests of thermal protection system (TPS) materials. TPDS consists of operational software and secured servers designed specifically to help manage facility data, facilitate customer data delivery, and act as a secure relational database for historical results at the Arc Jet Complex at the NASA Ames Research Center. The first operational deployment of TPDS will be completed by mid-summer of 2012. After deployment, TPDS will be operated and maintained by the Arc Jet Complex. TPDS has been designed to increase test facility efficiency, streamline facility-customer interaction, provide easy and secure access to data by the thermal protection system community, and enable discipline-advancing work. Future developments of TPDS could significantly increase efficiently across the TPS community and provide for additional discipline advancement. Connections to computational fluid dynamic simulation of arc jets will provide a validated archive of arc jet conditions based on a standard analysis approach. Thermal response modelers will have access to both validated environments and thermal response results for model development, verification, and validation. Statistical analysis evaluating model efficacy and material performance can be completed with confidence. Projects will have a data management tool that streamlines data delivery and archival while securing the critical data necessary for Certificate of Flight Readiness. Legacy results from previous missions will be archived and made available to the community for research, development, and planning. The TPDS has been implemented in collaboration between the Jet Propulsion Laboratory (JPL) and the NASA Ames Research Center (ARC), supported by the NASA Engineering Safety Center (NESC) and the Arc Jet Complex (Code TSF).

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